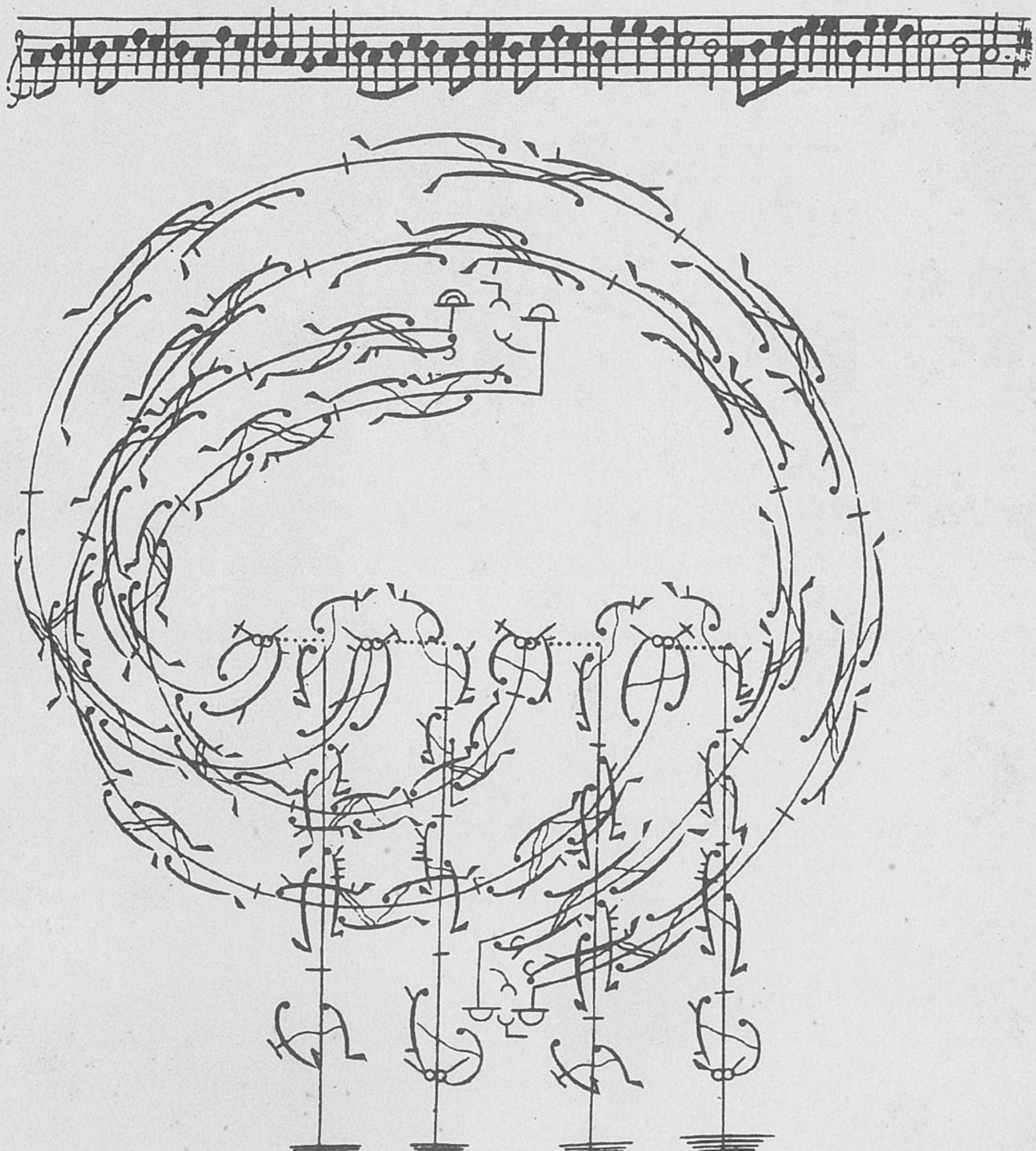
Semantics of Time, Space, Movement and spatio-temporal reasoning

Michel Aurnague, Andrée Borillo, Mario Borillo, Myriam Bras

SEMANTICS OF TIME, SPACE AND MOVEMENT

Groupe "Langue, Raisonnement, Calcul"

Toulouse



Sur la couverture : chorégraphie de Louis Pécour (1653 - 1729), peut-être pour "Thésée" de Lully. Notation de Raoul Auger Feuillet (1700).

SEMANTICS
OF
TIME, SPACE, MOVEMENT
AND
SPATIO-TEMPORAL REASONING

Michel Aurnague, Andrée Borillo, Mario Borillo, Myriam Bras
editors

Groupe "Langue, Raisonnement, Calcul"
Institut de Recherche en Informatique de Toulouse - CNRS et Université Paul Sabatier
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Le mois de Septembre est délicieux en Gascogne. Malgré le rythme plutôt excessif de nos travaux, sa douceur et ses couleurs ont imprimé au Workshop un agréable climat de bien-être auquel le charme du château de Bonas et les attentions dont Madame Françoise Simon a su nous entourer ont apporté la touche de civilité qui sied à la discussion scientifique.

Bien sûr, le programme était trop dense. Pour que nous ayions quand même pu, au terme de journées exténuantes, prendre un tel plaisir au concert du *TSM Art Ensemble* et à la conférence du Pr. Rémi Puech sur *"l'économie et la culture occitanes"*, il fallait que les talents des musiciens et du conférencier soient remarquables. Ils l'étaient et nous en gardons tous un souvenir particulièrement agréable.

Mais en pensant à ce Workshop et aux précédents, ce que notre groupe ressent peut-être le plus intensément c'est un sentiment de reconnaissance à l'égard des chercheurs qui, au fil de ces rencontres, sont devenus nos amis. Ils nous ont beaucoup aidé. Nous voudrions répondre à leur confiance en apportant notre touche personnelle aux recherches sur la langue, le raisonnement et la cognition qui nous passionnent tous.

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INTRODUCING
THE "LANGUE, RAISONNEMENT, CALCUL" GROUP

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The L.R.C. Group associates computer scientists and linguists working together on the analysis of the relations between meaning, logic and computation, on the basis of the formalization of the semantics of some linguistic expressions and the description of the logical structures of reasoning associated with them. The chosen domain is time, space and motion.

There are several reasons for this choice: first, the importance of these concepts for human communication and the fact that discourses must have a temporal-constrained structure, very often reinforced by spatial specifications. Moreover, if language mobilizes many resources to express these concepts, these are finite lexical and grammatical resources and can therefore be described in a systematic and progressive manner; and also, space and motion offer an ideal ground on which to confront linguistic expression and visual perception in a cognitive perspective.

a) Methodology is founded upon the analysis of the production of meaning in language carried out through a logical approach to natural semantics. Discourse representation theory (D.R.T.) allows a dynamic association of the representational and deductive components of semantics. The study of the computational properties of that formalism and its implementation makes possible the testing of certain precise relations between computation and cognition in discourse interpretation.

b) The ontology of spatial and spatio-temporal semantics defines the role of perceptual data in the models and the nature of their relations with other categories of information (functional and pragmatic ones). For this reason, spatial reasoning appears naturally as hybrid reasoning. Within this framework, the difficult mathematical and logical problems arising from the association of propositional and numerical structures can be dealt with in a particulary precise way.

c) Lastly, the analytic structure of spatial and spatio-temporal semantics can be used for experimental studies, in collaboration with cognitive psychologists and neuropsycho-linguists. These experiments should provide an additional empirical basis to these formalisms.

RESEARCH IN SEMANTICS AND LOGIC

1) Semantics of time, space and motion and spatio-temporal reasoning in language.

The objective is to describe progressively the resources available in language to express time, space and motion. From their systematic inventory conducted by ERSS linguists, we formally describe the mechanisms through which information and reasoning can be produced on these concepts. The cohesion of the architecture which permits the articulation of lexical, sentential and discourse levels is assured by an adequate theoretical framework (D.R.T., proposed by H. Kamp and its extension by N. Asher).

For time and motion, studies already carried out or in progress deal with :

- the semantics of some adverbs of temporal reference: *depuis (since), après (after), jusqu'à (until)*,... in their interactions with tenses and aspect (states, events, achievements, ...). The contribution of the semantics of these lexical components to the computation of the temporal structure of discourse has been implemented through the SCARTT system.

- the systematic description of a large class of prepositional verbs, *venir de (to come from), arriver (to arrive at), se diriger vers (to head towards)*,... has led to the precise definition of the respective roles of the verb and the preposition in the semantics of localization and motion, and to guide the computation of spatio-temporal inferences associated with them. This study, which also incorporates elements of grammatical tenses, is based on the mathematical structures of cognitive space (see below). It therefore proposes a semantics which renews studies on motion in AI.

- the temporal negation and its relation with presupposition. The logical and semantic study of this problem has just begun with negation adverbs *(ne pas (not), ne plus (no longer))*.

For the semantics of space, the general aim is to define the formalisms which provide a description of the different spatial configurations to which a linguistic marker refers, in such a way that spatial reasonings associated or produced by combinations of this kind of linguistic expressions can be calculated compositionally from the semantics of each of them.

Two large categories of linguistic expressions are being studied in a systematic manner. On one hand, relational markers, prepositions *(sur (on), dans (in), contre (against)* ...) and motion verbs (see above); on the other, some classes of referential terms such as internal localization nouns: *le sommet de (the top of), le bas de (the bottom* *of),* ... A comprehensive inventory of simple and compound prepositions in french has been achieved. The study of the relationship between the preposition and the nominal phrase introduced by it has produced a categorization founded on interesting semantic properties: distinction between internal and external localization, between static and dynamic relations, etc... A study of the anaphoric treatment of place complements in french shows a correlation between this categorization and conditions of application of the rules of anaphoric processing of the complement. The analysis of linguistic structures together with thought experiments associated with it, clearly shows the need for a logico-mathematical reconstruction of space, so that its formal properties fulfill the constraints of the cognitive space brought out by the expressive and inferential properties of language. The psychological experiments mentioned below (§ 3.2) will help to control the usual thought experiments. We have defined an original mathematical structure to describe and to associate the three components on which the model is founded:

- the topological and geometric level constructed on the mereological structures of the calculus of individuals (Leonard and Goodman, B.L. Clarke). It accounts for the position and the shape of portions of space occupied by objects, (using such notions as contact, boundary, direction and order on a direction ...).

- the functional level through which it is possible to express and to articulate on the preceding first level a certain number of properties of spatial entities in discourse, properties which guide the speaker's choice of such or such expression and influences its interpretation: deictic or intrinsic orientation of objects, their internal structure, the role of gravity and notions such as support, capacity...

- the interpretation of spatial expressions needs also a pragmatic level associating principles of communication (relevance, intentionality, ...) and shared knowledge (typicality of situations ...). The role of this component is to complete and refine the interpretation of the linguistic expressions produced by the first two levels, by adapting it to the situation of the discourse. Deductive mechanisms founded on conditional logic or default logic are being studied to enable automatic execution of the processes which dynamically adjust the recovery of lexical semantics on the level of discourse (cf 2.2 below).

2) Spatio-temporal reasoning and logic for discourse and dialog pragmatics.

2.1. Knowledge revision and dialog pragmatics.

What are the features of the reasonings necessary to answer questions on the properties of evolutive worlds, (specially spatio-temporal worlds) in such a way that the computation of the answer takes into account not only the available information about the evolution of the state of the world but also the implicit rules and conventions which we seem to use in dialogues ?

To satisfy these requirements we have defined a form of non-monotonic reasoning ("cartesian logic") in a first-order language with a clear denotational semantics, for which a demonstrator (sound but incomplete) has been fully implemented in Prolog. Knowledge and hypotheses, as well as deductive mechanisms, have been defined in agreement with the "cooperation principle" proposed by Grice, but adapted to the situation where the (human) speaker knows he is communicating with a machine.

2.2. Logic for discourse interpretation.

The theoretical framework for this work is the "Discourse Representation Theory" proposed by H. Kamp and its extension, the "Segmented DRT" by N. Asher, which defines a rigorous (formal) semantics for discourse. Each stage of the interpretation (DRS or SDRS) is constructed dynamically from the representation of the current sentence, interpreted in the context of the (preceding) sentences already interpreted. The recursive procedures bring into action, at the different levels, deductive mechanisms which compensate for the underspecification of the linguistic structures, but also integrate specific features of the discourse, rhetoric relations (narration, explanation ...) as well as pragmatic constraints (i.e. pertinence).

Studies under way start from the DICE system (Asher, Lascarides) and from studies on cartesian logic (Gaume) both to gain a deeper theoretical knowledge on the relationship between conditional and non monotonic logic, and to study the application to the SDRT of the "cartesian" demonstrator for the implementation of the calculus of temporal structures. The information provided by the lexical research (§1) is processed by these mechanisms. This also contributes to determine more precisely spatial and spatio-temporal relationship between discourse entities.

2.3. Event Calculus and Planning.

Event Calculus (Kowalski & Sergot) provides a non-monotonic temporal reasoning based on very general temporal concepts, such as linearity and density, and on the assumption that changes are exclusively produced by events (persistence axiom). We have extended this calculus in two ways. First, by defining a semantics of action more complex and realistic than the notion of elementary event, founded on the semantics of the linguistic expressions used to describe the actions. This semantics is completed at a pragmatic level by a technical interpretation in the context of action, which in this case is the planning of maintenance operations of transport aircrafts. Representation of the maintenance actions expressed in this way allows deductions on the possible evolution of the world (the state of the aircraft) which can precise their scheduling. These inferential mechanisms help to detect and to solve incoherences in the plan.

The second extension concerns the implementation of Event Calculus in logic programming with constraints. It brought us to study the complexity of different algorithms for Event Calculus and for actions scheduling.

3) Relationship between language and perception; spatio-temporal hybrid reasoning.

3.1. The project VILAIN (VIsion and LAnguage INtegration)

Our objective is to develop a system able to confront the linguistic expression of spatial and spatio-temporal information, such as *"le livre est sur le haut de l'armoire" (the book is on top of the cupboard)*, with the visual presentation and the manipulation of elementary scenes on a computer monitor which visualize the content of the linguistic message. The project starts with static scenes, later we will consider moving sequences. Simple linguistic expressions are formed by terms whose semantics has already been defined at the lexicon and sentence level (see § 1). Two modes have been chosen, interrogative (e.g: *is X in Y ?*), imperative (e.g: *put X to the left of Y*). To each mode corresponds a type of reasoning, after the semantics of the propositional content of the question or of the command has been calculated. For the treatment of questions, the reasoning module must verify the adequation of the visual scene to the content of the question. For the commands, the system has to carry out the visual transformations corresponding to them. Two kinds of formal structures are associated in these processings: propositional structures to express functional knowledge characteristic of objects X and Y (cf. § 1); and "pictorial" structures describing their shapes and their positions. Success or failure of each test will be judged on the adequation, for the subject, between his visual perception and the mental representation of his interpretation of the linguistic expression.

This project, which is in its early stages, poses a certain number of problems concerning the definition of formal languages and their semantics, associating in an coherent manner both the data structures and the mechanisms of logic (for propositional knowledge) and the numerical data and numerical calculus (at least to manipulate the pictures on the screen). These theoretical problems are crucial for the understanding of the hybrid reasoning put into play in multimodal communication.

A more applied study on this subject is in progress. For a certain type of situation, the objective is to produce automatically a symbolic (propositional) description of a scene from its numeric description and from the knowledge associated to the spatial entities which are represented. Information relative to the intentions of the agent will be introduced at a later stage in the interpretation of the scene.

3.2. Psychological and neuropsychological bases of the ontology of space.

The main purpose is to conceive experimental protocols in which subjects are presented elementary pictures illustrating the use of a localization expression (*le haut de X, (the top of X), le devant de X (the front of X)*)or of a spatial relation (*X dans Y (in), X sur Y(on), X contre Y (against)*). Each set of elementary figures is based on the permutation of some primitive concepts of the formal model of the expression. The analysis of the subjects' behaviour (failure rate, time of response) should lead us to test, from the point of view of human cognition, the empirical significance of the primitive concepts which define the ontology of those linguistic markers. Studies have been carried out in direct collaboration with the Centre de Recherche en Biologie du Comportement (B. Thon) for spatial prepositions and with the Laboratoire de Neuropsycholinguistique Jacques Lordat (J.L. Nespoulous) for nouns and adjectives of internal localization.

LINGUISTIC ENGINEERING

These studies have started more recently. They are mostly carried out in the framework of ARAMIIHS Laboratory (UMR 115, CNRS). Their objective is to develop some applications of computational linguistics to new technological needs in NL processing.

Studies develop in two directions. The first concerns the development of extended terminological data bases for technical languages, in the field of space technologies. The objective is to build progressively a set of tools necessary for the processing of linguistic material in this domain, the most elementary one being the terminological normalization of technical texts, from their computer-aided writing to their automated modification (updating).

The second line of research is more ambitious and deals with the transition from informal (i.e. written NL) to formal software specifications. At the conception stage, software requirements are usually expressed through well-structured sets of short technical texts, with strong constraints on their terminological resources and their syntactic structures defined according to professional norms (IEEE, NASA...). The extraction and the representation of the information content is thus more accessible than in the case of free (unconstrained) texts. Representations obtained in this way are used to control some properties of the (informal) natural language specifications. For instance, traceability links or detection of incoherences can be operated through algorithms. At a later stage, this kind of procedures will help to facilitate the expression of formal specifications.

FUTURE PROJECTS

As these studies develop in the next few years, the major areas of research will be :

- The extension of the linguistic and semantic coverage of temporal, spatial and spatio-temporal markers in french. We will start a comparative study of the cognitive structure of these concepts in some other languages (spanish, basque) and see what consequences this may have on formal ontology and inference mechanisms.
- The development of studies on computer science and logic. First, to specify and to implement the mechanisms of the construction of DRS and SDRS, but also, to precise the relations between the different types of logic necessary for a dynamic integration of linguistic and metalinguistic information in the interpretation of discourse.
- The development of the VILAIN system, with particular attention given to the theoretical questions arising from hybrid reasoning. The development of applications including multi-modal communication will enable us to deal with these problems when the intentions underlying dialog are of a more specific nature.
- The development of our work in collaboration with psychologists and neuro-psychologists on the empirical foundations of the formal semantics of space and the confrontation between language and visual perception in some aphasia cases.

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I

SPACE AND MOVEMENT IN LANGUAGE

Christoph Schwarze

Time, Space and Order in the Lexicon

0. Introduction

Recent linguistic work* on the expression of temporal and spatial concepts has brought about a rich knowledge about these concepts and about the ways in which they are encoded. Looking at the results of this research, one may be puzzled why languages have developed such sophisticated means of expression for spatial and temporal concepts. In fact, if we are not philosophers, there does not seem to be a particular point in giving attention to space and time and in talking about them for their own sake. Obviously, the linguistic means of spatial and temporal reference have not originated in order to make it possible for us to talk about space and time. So what else is the raison d'être for this large amount of linguistic apparatus for spatial and temporal reference? The answer is that we use space and time essentially as *background systems*. In this view, space and time have basically two purposes: we need them for describing and for localizing the objects (in the broadest sense) we talk about[1].

In this paper, I will focus upon localization, and I will only make some allusive remarks on the descriptive functions of space and time.

1. Identification, description and localization

The speaker who wants to refer to a specific object in a given situation, must get the hearer to identify this object. This can be done by using expressions which specify properties of the object. Pragmatically, we can distinguish two kinds of properties: descriptive and localizing properties.

Descriptive properties are inherent to objects, such as size, color, form, etc., or relational, such as origin, typical use, ownership, etc. *Localizing properties*, in a first approximation, are those properties which specify an area where the object can be found. In other words: we identify an object by saying what it is and where it is. To give an example: When we utter an expression like

(1) The low building at the end of the driveway is a garage

* I want to thank Bruce Mayo for correcting my English and for contributing the definitions of the Prolog predicates `follow(a,b,s)` and `next(a,b)`, with are mentioned in the text and fully given in the Appendix.

[1]This idea has also been expressed by Croft 1990: 256ff. His terminology slightly differs from mine. What he calls "situating entities" and "background systems" is termed "localizing objects" and "background dimensions" in the present paper. But there is a major difference: whereas Croft claims that "situating in space, time and mental space" are "(minor) propositional acts" (cfr. p. 273), the present study does not restrict localization to the realm of pragmatics, the basic assumption being that we use the same type of semantics for communicative as well as for cognitive purposes.

we use the words *low building* for describing and the words *at the end of the driveway* for localizing the object we want to refer to.

But Time and Space are not essential for *describing*. In order to specify the descriptive properties of objects, we mostly use concepts of natural kinds, artifacts (like 'garage'), substances etc., and additional concepts such as size, form, color etc. But some of these concepts, again, need Space as a background-system. This holds for the concepts of size and form; dimensional adjectives are typical examples.

In the broad sense in which I use the term object, it also includes events. We describe events using concepts of event types, and Time is a background-system for the definition of event types (cf. the distinction between state and process in verb meanings). Time is also involved in the meanings of words like *fast* and *slow*.

2. Localization domains

Background-systems for localization will be called *localization domains*. Time and Space are the most important localization domains, but there also are minor localization domains, including *Order*, as expres-sed by the ordinal numbers, by adjectives like *last*, or by prepositions like *before* and *after*[2].

The three localization domains can be distinguished from each other with respect to their intrinsic nature, to the kinds of objects that they may localize and to their status in language. Let me just give a sketchy characterization of the three domains, which, of course, does not claim to be original.

Space is three dimensional. It provides *places* for material objects and for observable events. A place is a relation between an object or an event and a segment of space. This segment of space can be defined in various ways. The ways language prefers are pointing at that segment of space (deictic expressions) or describing it as a region, i.e. as being related in some specific way with some other object (prepositions). Concepts of space are abundantly lexicalized, and the lexicon of space spreads over a large range of lexical categories[3].

Time is one dimensional. It localizes events, and it may also localize a subset of properties and a subset of individuals, namely those properties and individuals which can undergo change (cf. *the former president, post-war Europe*). There is a relation which is comparable to "place", namely *moment*. A moment is a relation between an event (or an

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[2]Croft 1990 postulates, along with Space and Time, a "background dimension" Mental Space. He does not discuss Order as such, and he seems to think (p. 257) that words like *before* and *after*, *precede* and *follow* only refer to temporal relationships. I will claim, in section 4.2 below, that the French equivalents of these words do not refer exclusively to Time.

[3]This has been shown, e.g., in Schwarze 1991, for the concept of region.

individual) and a segment of time. That segment of time may be identified as some temporal object (e.g. a certain day) or by its relationship with some other segment of time. Concepts of time probably are less abundantly lexicalized than concepts of space; but they are essential for the semantics of tense.

Order also is one-dimensional. It may localize all kinds of objects: physical objects, events, letters, numbers, days, months, etc. It does so by a relation which I will call *position*. A position assigns to the localized object a value in a *sequence*. There are two kinds of sequences: sequences the elements of which are instances of the same basic category (e.g. a sequence of bus-stops), and sequences which contain entities of different basic categories (e.g. a sequence of landmarks in a route description). Some sequences must be constructed or perceived in the current situation (e.g. in route descriptions), others are conventionally or naturally given (the alphabet, the sequence of the year's seasons). Positions are identified with respect to other entities in the same sequence or by counting[4]. Examples are:

(2) In the Arabic alphabet, *h* is after *w*

(3) In the Arabic alphabet, *h* is the 27th letter

In (2) and (3), the expression *in the Arabic alphabet* refers to a sequence, whereas the rest of each sentence specifies the position of the letter *h*.

In language, concepts of Order are expressed by those adjectives which denote ordinal numbers, by certain prepositions (e.g. *before, after*) and by verbs (e.g. *precede* and *follow*).

According to this analysis, all properties of localization have the same general structure[5], namely:

(4) Localization (x, d, Q (x, a))

where x is an object (in the broadest sense), d one of the localization domains Space, Time or Order, Q a predicate variable for Place, Moment or Position and a what may be called the area occupied by x.

---

[4]Like Space and Time, Order is not only a domain of localization, but also a background system for describing, namely for defining the beginning and the end of objects. Words like *begin* and *end* lexicalize concepts of Order for this purpose.

[5]Here and throughout this paper, I use a notation which corresponds to or is derived from Prolog rules. A Prolog II program which expresses the main ideas of the present study as well as the results of some tests of that program are given as an Appendix of this paper.

Each domain of localization selects its own *Q*. Space selects Place, Time selects Moment, and Order selects Position. (As will be explained later, these simple stipulations may be conceptually modified.)

Each single localization property also specifies *a*, directly, or as a relation. Thus the localizations in (2) and (3) have the following forms:

(2') Localization (*h*,Order, Position(*h*, after(*h*,*w*)

(3') Localization (*h*, Order, Position(*h*, 27))

In discourse, when the localization domain is Order, the hearer must be able to identify the sequence. If this is not possible from the context, the sequence may be referred to by an adjunct, as in:

(5) Jean était avant Paul {dans la file des coureurs, dans la queue, sur la liste}
'Jean was before Paul {in the line of runners, in the queue, on the list'

In (5) the sequence is characterized as a line, or as a queue, or as a list. But it is not fully specified. It is, in fact, not necessary for communication to know the extension of the sequence; it suffices to know some relevant parts. This can easily be shown with respect to the use of ordinal numbers: we do not need to know how many bus-stops there are in order to successfully use expressions such as *the first bus-stop, the second bus-stop*, and *the last bus-stop.*

The following Prolog rules summarize the general frame-work which has been developed so far:

(6)
```
localization(x,space,place(x,a))->
     physical-object(x);
```

(7)
```
localization(x,space,place(x,a))->
     event(x);
```

(8)
```
localization(x,time,moment(x,a))->
     event(x);
```

(9)
```
localization(x,order, position(x,a))->
     sequence(s)
```

```
arg(n,s,x)
```
[6];

3. Kinds of interaction between localization domains

In the structure and use of language there are two kinds of interaction between domains of localization: analogy and application.

3.1 Analogy

Analogy takes place when we use an expression *e* of domain *d1* in domain *d2* in such a way that the original concept expressed by *e* necessarily undergoes a modification. This is the case in examples like the following:

(10) Jusqu'*ici*, tout s'est passé à souhait
'until now, everything went as well as one could wish'

(11) *Au-delà* de 200 frs., un repas doit être vraiment exceptionnel
'above 200 frs., a meal must really be exceptional'

In (10) *ici*, which is a spatial expression, is used within the domain of Time. The origo towards which it points is no longer spatial but temporal. In (11) *au-delà de*, which also belongs to the domain of Space, is used within the domain of (numerical) Order. In its original meaning, it refers to some material obstacle, such as a fence, a river or a mountain range. When used as in (11), it refers to some value which is considered as a limit.

It is well known that the domain of Space is an important source of analogy, and that a large amount of polysemy is due to lexicalized analogical use; cf. the spatial and temporal meanings of the words for 'in', and 'to go' in various languages, or the spatial and the sequential meanings of French *partir* in *partir pour* 'to leave for' and *à partir de* 'from'. Additionally, relations of Order often are expressed by words which, in a diachronical perspective, belong to the vocabulary of Space, such as French *d'abord* 'first, initially, in the first place', which is derived from *aborder* 'to reach, to approach', originally 'to get on board'.

3.2 Application

Application takes place when we use an expression *e* of domain *d1* in domain *d2* in such a way that the concept originally expressed by *e* does not undergo a modification. This is the case in examples like the following:

---

[6]For readers who are not familiar with Prolog II: arg(n,s,x) is a built-in predicate. If *n* is a number >0, it reads as follows: *x* is the n^{th} element of sequence *s*.

(12) John will leave after Christmas

(13) John stopped after the first block

The preposition *after* belongs to the domain of Order. In (12) it is applied to the domain of Time, and in (13) to the domain of Space. The application has as a consequence that the phrase with *after* may answer a question with *when?* in (12) and with *where?* in (13). But, according to the definition of application, the relation 'x after y' is the same in both examples. What changes, is not the relationship itself but the localization domain within which it holds and the arguments which it selects. This can be expressed by the following Prolog rules:

(14)
```
localization(x,time,<moment,x,<after,y>>)->
    event(x)
    temporal-object(y);
```

(15)
```
localization(x,space,<position,x,<after,y>>)->
    physical-object(x)
    physical-object(y)
    sequence(s)
    element(x,s)
    element(y,s);
```

As one can see, 'after' is applied within the localization domain of Time in (14) and of Space in (15); there is no need to say that there are two different relations.

I will not, however, use rule (15) in order to account for the application of 'after' within the domain of Space. The relation of position, in fact, essentially belongs to the localization domain of Order, as exemplified by (3) and represented by (9) above. The existence of a sequence, as postulated in (9), is required in all applications of 'after'. When 'after' is applied within the domain of Time, a sequence is implicitly given; we might represent that sequence as part of the relation 'moment'. The application of 'after' within the domain of Space may now be accounted for by, instead of a rule like (15), a general rule of derivation, namely:

(16)
```
localization(x,space,p)->
    localization(x,order,p);
```

As will be shown in the following section, this conceptual framework will make it unnecessary to consider some prepositions and verbs as polysemous.

4. The domain of Order in the French Lexicon

I will now apply this conceptual framework to the French lexicon, especially to the lexicon of Order. French expresses 'position' by ordinal adjectives (*premier, deuxième,* etc.). It can express the notion of precedence ('before', 'after') by prepositions (*avant, après*), adjectives (*précédent, suivant, prochain*) and verbs (*précéder, suivre*), and it has prepositions which define subsequences or boundaries of sequences (*jusque, à partir de*). In this paper, I will concentrate on ordinal adjectives and the expression of precedence.

4.1 Ordinal adjectives

The primitive ordinal adjectives of French are a set of three words, *premier, second, tiers*, the rest being obtained by suffixation of the names for cardinal numbers (e.g. *quatrième*)[7].

The semantic structure of ordinal adjectives has already been given above in (2'); I repeat it in a more more general form:

(17) Localization (x, Order, Position(x,n)
where n is a number.

Syntactically, x is a noun, and n is an adjective which modifies that noun[8].

The adjective *dernier* 'last' is closely related to the class of ordinal adjectives. Its semantic structure is similar to (17), but the position of x is not a number[9]. It is defined a position such that there is no position after it:

(18) Localization (x, Order, Position(x, n) & $\neg\exists$ y After(y, n)

---

[7]This list is even smaller if we take into account that besides *second* there is *deuxième*, with a difference of meaning, and that the use of *tiers*, which has been replaced by *troisième*, is extremely restricted.

[8]The Prolog implementation given in the Appendix does not contain a treatment of ordinal adjectives, because this would have required a more sophisticated treatment of noun semantics. This is due to the fact that ordinal adjectives refer to sequences of instances of the same basic category. The elements of sequences of this kind do not represent the meaning of nouns. They are just constants which are arguments of the same predicate, which represents the meaning of a noun. To give an example: *la troisième station* 'the third station' must be represented as 'the individual which is third in a sequence of individuals which all are stations'.

[9]One might be tempted to analyze *last* as referring to the highest number contained in a sequence. But, as mentioned above, we do not need to count in order to identify the last position in a sequence.

Ordinal adjectives have applications into Time and Space: they are freely used outside the domain of Order (e.g. in *the third day, the first door*)[10].

There also is some analogical use. *premier* and *dernier* may be used to express judgments of quality or importance (e.g. *le premier port de pêche du pays*), and *trente-sixième* may express insignificance (*un pays de trente-sixième catégorie*).

Cognitively, one can also count back from the last position. Lexically, French has only one word for this purpose, namely *avant-dernier*, which counts back one unit. In comparison, German has a compounding device which makes it possible to go back as many units as one wants (*der letzte, der vorletzte, der drittletzte*, etc.). The absence in French of such words is easily explainable by the poorness of compounding in that language. But it must be observed that the ordinal adjectives generated by German word-formation are not used if they do not denote relatively small numbers. Beyond lexical structure there certainly is a general cognitive constraint: humans count more easily in an ascending than in a descending order.

4.2 The lexicon of precedence

4.2.1 Prepositions of precedence

The predicates 'before' and 'after' are typically expressed by the prepositions *avant* and *après*. Their basic semantic analysis has already been discussed. In a Prolog notation (where some of the syntactic information is omitted), their lexical descriptions are, respectively:

(19)

```
prep("avant",localization(a,order,<position,a,<avant,b>>))->
        sequence(s)
        follows(a,b,s);
```

(20)

```
prep("après",localization(a,order,<position,a,<apres,b>>))->
        sequence(s)
        follows(b,a,s);
```

where *a* appears as an external argument and *b* as the direct object of the preposition.

---

[10] It is true that in English no noun phrase containing an ordinal adjective can answer questions with *where?* or *when?*, but this might be a question of syntax. - In French, *la troisième journée* can answer a question with *quand?*

Avant and *après* can be be applied to Space (21) and Time (22)[11]; in fact, *avant moi* in (21) can answer a question with *où?* and *avant dix heures* in (22) a question with *quand?*

(21) Il était avant moi dans la file
'he was before me in the queue'

(22) Téléphonez-moi avant dix heures
'Call me before ten o'clock'

But there must be a motivation for the hearer to accept this application. From the two sentences (23) and (24), only (23) is acceptable without further context:

(23) Je m'arrêtai avant le pont
'I stopped before the bridge'
(24) ? Je me trouvais avant le pont
'I was before the bridge'

The condition for spatial uses of *avant* is obviously that there be a sequence, which in (23) can easily be identified as the path of the motion to which the verb *arrêter* refers. The oddity of (24) is due to the fact that there is no such cue in the sentence. Temporal application, of course, is always possible, since Time can always be viewed as a sequence.

Now how does application of Order into Space and Time work? According to the principle of application, we do not treat *avant* and *après* as polysemous. We will simply formulate additional entries for the application to Time, whereas the application to Space follows from rule (16). The additional entries are:

(25)
```
prep("avant",localization (a,time,<moment,a,<avant,b>>))->
        event(a)
        temporal-object(b);
```

[11] A similar analysis of *avant* and *après* has already been proposed by Vandeloise 1986: 160ff. Vandeloise correctly observes that these prepositions may also be applied to other domains, e.g. ranks in competition, and he gives a detailed discussion on the various kinds of scales to which *avant* and *après* may refer.

(26)

```
prep("après",localization (a,time,<moment,a,<apres,b>>))->
        event(a)
        temporal-object(b);
```

4.2.1 Adjectives of precedence

The adjectives of precedence are *précédent, suivant* and *prochain*. They seem to differ from *avant* and *après* only in their syntactic form, the concepts expressed being the same; cf. (27) and (28):

(27) {Le mot précédent, le mot avant} est illisible
'the word before is illegible'

(28) {Le mot suivant, le mot après} est illisible
'the following word is illegible'

But there is a slight difference in meaning: *précédent* and *suivant* additionally give the information that the two positions involved are contiguous in the sequence[12]. One does not use a sentence like (29) when one wants to compare the gas prices of, say January and May:

(29) Le mois précédent, l'essence avait encore coûté beaucoup moins cher
'the month before, gasoline still had cost much less'

The meanings of *précédent* and *suivant* might therefore be represented by introducing the relation 'next'; cf. the following lexical entry for *précédent* in a Prolog notation:

(30)

```
adj("précédent",localization (a,time,<moment,a,<avant,b>>))→
        sequence(s)
        follows(b,a,s)
        next(a,b);
```

---

[12]It is true that *avant* and *après* also are often interpreted with respect to contiguous positions. If I drive along a row of five buildings, and I say *je me suis arrêté après le deuxième immeuble*, I ordinarily do not mean that I stopped after the third building. But this is only a default assumption. This can be shown by a slightly modified example: If I walk in the street, looking for an address which I do not remember exactly, I may say: *je suis sûr que c'était après le deuxième immeuble*, just meaning that the address is not before the third building and may be in any of the following ones.

Application is possible. The two adjectives are equally natural in the domains of Time and Space[13]:

(31) le mois {précédent, suivant}
(32) la maison {précédente, suivante}

As to *analogical* use, one should expect that it cannot take place, if it is correct that *précédent* and *suivant* primarily belong to the domain of Order. In fact, analogy is restricted to those items which originally belong to the domain of Space, and no examples of analogical use of *précédent* or *suivant* could be found.

Let us now consider *prochain*. Its meaning is quite similar to the meaning of *suivant*. But there is an important difference, which the following examples will illustrate:

(33) Nous publierons la suite de cet article dans notre prochain numéro
'this article will be continued in our next issue'

(34) Pardon, Monsieur, vous descendez à la prochaine?
'Excuse me, Sir, do you get off at the next station?'

(35) Je reviendrai lundi prochain
'I will come back next Monday'

These sentences become very odd if we replace *prochain* with *suivant*, and example (35) becomes even ungrammatical:

(33') ? Nous publierons la suite de cet article dans notre numéro suivant
(34') ?? Pardon, Monsieur, vous descendez à la suivante?
(35') *Je reviendrai lundi suivant

Consider now the following sentences:

(36) Voici le numéro du "Monde" du 13 septembre. Je n'ai pas pu trouver les numéros suivants.
'This is the issue of "Le Monde" from September, 13. I could not find the following issues.'

[13] The question test does not work here. A possible, but complicated test would be to try to reformulate the sentence with *avant* and look whether the prepositional phrase thus obtained answers a question with *où* or *quand*. I think however that the intuition is safe.

(37) Me rendant compte que je m'étais trompé de ligne, je descendis à la station suivante.
'Realizing that I had taken the wrong line, I got off at the following station'

(38) J'y suis retourné le lundi suivant
'I returned there the following Monday'

These sentences become odd if *suivant* is replaced with *prochain*:

(36') ? Voici le numéro du "Monde" du 13 septembre. Je n'ai pas pu trouver les prochains numéros.

(37') ? Me rendant compte que je m'étais trompé de ligne, je descendis à la prochaine station

(38') * J'y suis retourné le prochain lundi

The explanation of these observations is that *prochain* is deictic. This adjective means, intuitively speaking, 'the following one, counting from where we are'. In other words, *le prochain x* presupposes that the speaker treats as a deictic origo a position in the sequence in which x is localized. This is particularly well shown by sentences (35) and (38). In fact, the names of the days of the week are used without an article if the interpretation is deictic. In (39) *lundi* is the next and in (40) it is the last Monday from now:

(39) Elle arrivera lundi
'she will come on Monday'

(40) Elle est arrivée lundi
'she came on Monday'

With the indefinite article, as in (41), *lundi* denotes just some Monday, and with the definite article, as in (42), there is a kind of universal quantifier:

(41) Elle est arrivée un lundi
'she came on a Monday'

(42) Elle vient le lundi
'she comes on Mondays'

Now the trouble with (35') and (38') is that there is a clash between an expression which requires a deictic and another expression which requires a non-deictic interpretation.

The adjective *prochain* has yet another peculiarity. We have seen that *suivant* is converse to *précédent*. One would expect then that there also is a lexical item which is converse to *prochain*. But there is none. However, French uses its possibilities of word order to fill this gap. Indeed, the adjective *dernier*, as a kind of ordinal adjective, precedes the noun, like all ordinal adjectives. If it follows the noun, it is deictic:

(43) a. C'était le dernier dimanche de septembre
'it was the last Sunday of September'
b. Elle est arrivée dimanche dernier
'she arrived last Sunday'

(44) a. C'était pendant la dernière semaine de son séjour
'this was during the last week of his stay'
b. C'était la semaine dernière
'that was last week'

So *prochain*, the lexical expression of 'a after b' with a deictic *b*, has no lexical converse counterpart. And, what is more, the syntactic expression of 'a before b' with a deictic *b* has restrictions which *prochain* has not: postnominal *dernier* is natural only with a small number of nouns which all denote units of Time: the names of the days (*lundi dernier*). the names of the months (*en janvier dernier*), and of the seasons (*au printemps dernier*). and the nouns *journée, nuit, semaine, mois, an, année* and *siècle*.

It may sound surprising that deixis should appear not only in the lexicon of Space and in the semantics of tense and person, but also in so abstract an area as the localization domain of Order. But whenever we mentally run through some sequence with the elements $e_1 \ldots e_n$, there always is an element e_i which we have just reached. Now why shouldn't we be able to stop at some e_i and look at the other elements from there?

4.2.2 Verbs of precedence?

The predicates 'before' and 'after' can also be expressed by the verbs *précéder* and *suivre*; cf.

(45) A mesure que l'on s'éloignera davantage de la valeur moyenne (...) les valeurs particulières deviendront (...) plus distantes de celles qui les précèdent ou qui les suivent (TLF)

'as one moves farther away from the average value, the particular values will become more distant from those which precede or follow them'

(46) Les notes qui suivent le texte (TLF)
'the notes which follow the text'

The two verbs[14] can be used with respect to Time:

(47) Dans le mois qui précéda Waterloo (TLF)
'in the month preceding Waterloo'

(48) Le jour qui suivit (TLF)
'the day which followed'

For spatial uses, there is a clear difference between *précéder* and *suivre*: *suivre* quite naturally expresses the predicate 'after' in spatial contexts (49), whereas application of *précéder* to Space is restricted. If the subject of the sentence denotes an object which generally is not supposed to move, *précéder* is rather odd (50):

(49) La maison qui suit la mienne (TLF)
'the house which follows mine'

(50) ?La maison qui précède la mienne
'the house which precedes mine'

If the subject of the sentence denotes an entity which can undergo motion, *précéder* systematically denotes motion, and may have the typical arguments of a verb of motion, as well as an indication of distance:

(51) Il me précéda dans la salle
'he entered the room ahead of me'

(52) Il me précéda d'une centaine de mètres
'he was ahead of me by about one hundred meters'

---

[14]Vandeloise 1986: 166f. observes that certain uses of *avancer* refer to temporal order. His examples are: *le ministre avance la réunion* 'the minister brings forward the date of the meeting' and *la montre du curé avance* 'the priest's watch is fast'. But in terms of the terminology I introduced above *avancer* is not primarily a verb of Order. In its basic meaning it is a verb of causative motion, and the temporal readings are results of analogy.

Furthermore, *suivre* also has these constructions:

(53) Il me suivit dans la salle
'he entered the room behind me'

(54) Il me suivit d'une centaine de mètres
'he was walking about one hundred meters behind me'

These observations suggest not to consider *précéder* and *suivre* as simple verbs of Order, but as verbs of *motion* which incorporate predicates of Order, and which can be used within the localization domain of Order by virtue of a conceptual shift. In other words: In their basic meanings, *précéder* and *suivre* amalgamate concepts of Order with the concept of motion. They have derived meanings in which the concept of motion has faded away. On the other hand, as has been shown above, the adjectives derived from their present participles express simple concepts of Order, and may receive spatial or temporal interpretations by application. I will come back to this problem in the last section of this paper.

5. Localization domains and semantic change

The picture which results from the above analysis can be summarized as follows:

a. There are three domains of localization, each of which has its own means of expression. Lexical items belonging to the domain of Order can receive spatial or temporal interpretations by application. On the other hand, lexical items belonging to the domain of Space can receive non-spatial interpretations, including Order, by analogy.

b. The lexical items which belong to the domain of Order have an asymmetry in their deictic subsystem. Another asymmetry appears in the system of ordinal adjectives.

c. There are two verbs of motion which undergo analogy in such a way that they can conventionally be used in the localization domains of Time and of Order, the latter use being heavily restricted.

How can such a situation be explained? A glance at lexical evolution may give us an answer. When we look at the etymologies of the French lexicon of Order, we find that all items, except genuine ordinal adjectives, had a more concrete meaning sometime in their history. Let me briefly state the relevant facts.

dernier is derived by suffixation from OFr. *derrain* 'last', which developed from Vl. *deretranu*, an adjectival derivation from *de retro* 'back'. This latter phrase also gave origin to French *derrière* 'behind'. We may thus conclude that *dernier* goes back to a word which expressed a spatial concept[15].

avant has developed from Vl. *ab ante* 'from the front', a variant of *de ab ante*, from which French *devant* 'in front of' has derived. Lt. *ante*, which is the nucleus of both, had basically a spatial meaning, but also various non-spatial meanings based on analogy. Whether *avant* is directly a result of the analogy from Space to Order, or whether it continues and has lexicalized one of the non-spatial meanings of *ante*, is not an important question for this overview, its meaning having developed, in both cases, out of a spatial concept.

après is Vl. *ad pressum*, the nucleus of which is the past participle of *premere* 'to press'. There is an intermediate meaning 'close', still alive in French *près de*. This meaning rests upon a kind of metonymy: objects which are pressed together are close together. The step from 'close' to 'after' may be explained by the assumption that 'close' was first restricted to nearness in linear structures and then to the concept 'behind', the third step being an analogy from Space to Order[16].

prochain comes from Vl. *propeanu*, an adjective which is derived from the Lt. adverb *prope* 'near'. Like *ante*, *prope* has non-spatial readings, but in some way the meaning of *prochain* rests upon an analogy from Space to Order[17].

Let me also mention that *jusque*, which I did not analyze here, but which certainly is narrowly connected with the lexicon of Order and can be applied to Space as well as to Time, goes back to the lexicon of motion: Its nucleus, Lt. *usque*, contains *us*, which is reduced from *ubs*, the locative of *ubi* 'in what place'. Thus another word for a most abstract concept of Order stems from the lexicon of spatial localization.

These facts of lexical change are sufficient evidence to conclude that the lexicon of Order, at least partly, grew out of the lexicon of Space by semantic change. We may even imagine a phase of evolution in which there was no specific lexicon of Order and where ordering had to be expressed exclusively by analogical use of the lexicon of Space. We can assume, furthermore, that lexicalization of those analogical uses gave raise to the lexicon of Order. If Modern French shows some puzzling gaps in this lexical subsystem,

---

[15]This is a very simplified presentation. The first syllable of Lt. *retro* is the same as the prefix *re-*, *red-*, which is found in many verbs. It already has a rather abstract and polysemous meaning, namely 'again' (i.e. repetition) or 'against' (i.e. opposition). But I think that it could be shown that Vl. *de retro* had a concrete spatial meaning.

[16]It is interesting to see that in Latin one of the meanings of *premere* was 'to pursue closely'. Therefore the semantic shift might have been more direct than the one I postulate. But it still would hold that there is an analogy from Space to Order.

[17]In Modern French, the adjective for 'near' is *proche*, a reduced variant of the form *prochain*. The lexical differentiation between the words for 'near' and 'next' did not take place before the 14th century.

this can be globally explained by assuming that this process has advanced very far, but has not yet run to completion.

The absence of a lexicalized expression for backward deixis as well as the sparseness of the items available for counting backward can probably be explained, as I said above, by a general cognitive constraint "rather go forward than backward".

And the fact that *précéder* and *suivre*, unlike *précédent* and *suivant*, strictly speaking, do not belong to the lexicon of Order can be explained with respect to the semantics of parts of speech: *précéder* and *suivre* express Order only by analogy, because they are verbs. Concepts of simple order are static, but typical verbs express more or less dynamic processes. On the other hand, the two adjectives which are derived from *précéder* and *suivre* were liable to loose their association with the concept of motion just because they are adjectives and, as such, are untypical means for the expression of motion.

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TLF = *Trésor de la langue française. Dictionnaire de la langue du XIXe et du XXe siècle.* Paris: Centre National de la Recherche Scientifique

Appendix : The program LEXICALIZED CONCEPTS OF LOCALIZATION

The program consists of two parts. Part one (sections 1. - 4.) represents *conceptual* structure. It localizes objects and events with respect to Space, Time and Order. Part two (sections 5. - 6.) represents *linguistic*, that is, semantic and syntactic structure. It interprets sentences which localize objects of various kinds and events with respect to Time, Space and Order.

```
"1. Various kinds of localization"

localization(x, space, <place,x,<devant,y>>) ->
   physical-object(x)
   physical-object(y)
   dif(x,y)
   ;
localization(x, space, <place,x,<dans,y>>) ->
   physical-object(x)
   physical-object(y)
   dif(x,y)
   ;
localization(x, space, <place,x,<devant,y>>) ->
   event(x)
   physical-object(y)
  ;
localization(x, space, <place,x,<dans,y>>) ->
   event(x)
   physical-object(y)
   ;
localization(x,time, <moment,x,y>) ->
   event(x)
   temporal-object(y)
   ;
localization(x,time, <moment,x,<avant,y>>) ->
   event(x)
   temporal-object(y)
   ;
localization(x,time, <moment,x,<apres,y>>) ->
   event(x)
   temporal-object(y)
   ;
localization(x, order, <position,x,<avant,y>>) ->
   sequence(s)
   follows(x,y,s)
   ;
localization(x, order, <position,x,<apres,y>>) ->
   sequence(s)
   follows(y,x,s)
  ;
localization(x, space, p) ->
   localization(x, order, p)
   physical-object(x)
   ;
follows(a,b,c1) ->
   member(a,c1,c2.c3)
   member(b,c3,z)
   ;
member(a,a.r,a.r) ->;
member(a,b.r1,c) ->
   bound(r1)
   member(a,r1,c);
```

```
next(e1,e2,e1.e2.r2)->;
next(e1,e2,e3.r2)->
   bound(r2)
   next(e1,e2,r2);

"2. Various kinds of individuals"

physical-object(pont)->;
physical-object(gare)->;
physical-object(carrefour)->;
physical-object(tour)->;

day(lundi)->;
day(mardi)->;
day(mercredi)->;
day(jeudi)->;

mois(janvier)->;
mois(fevrier)->;
mois(mars)->;
mois(avril)->;

temporal-object(x)->
   day(x);
temporal-object(x)->
   mois(x);

event(rencontre)->;
event(excursion)->;
event(soiree)->;
event(aperitif)->;

letter(alpha)->;
letter(beta)->;
letter(gamma)->;
letter(delta)->;

number(1)->;
number(2)->;
number(3)->;
number(4)->;

"3. Some sequences"

sequence(lundi.mardi.mercredi.jeudi.nil)->;
sequence(janvier.fevrier.mars.avril.nil)->;
sequence(1.2.3.4.nil)->;
sequence(pont.gare.carrefour.tour.nil)->;
sequence(alpha.beta.gamma.delta.nil)->;
sequence(rencontre.excursion.aperitif.soiree.nil)->;


"4. Asking some easy questions"

about(x,y)->
   localization(x,u,y)
   ;
where-is(x,y)->
   localization(x,d,place(x,y));
```

```
where-is(x,y)->
    localization(x,space,position(x,y))
    ;
when-is(x,y)->
    localization(x,time,moment(x,y))
    ;

"5. A fragment of French"

prep("devant".x,x,localization(a, space, <place,a,<devant,b>>))->
    physical-object(a)
    physical-object(b)
    dif(a,b)
    ;
prep("devant".x,x,localization(a, space, <place,a,<devant,b>>))->
    event(a)
    physical-object(b)
    ;
prep("dans".x,x,localization(a, space, <place,a,<dans,b>>))->
    physical-object(a)
    physical-object(b)
    dif(a,b)
    ;
prep("dans".x,x,localization(a, space, <place,a,<dans,b>>))->
    event(a)
    physical-object(b)
    ;
prep("en".x,x,localization(a,time,<moment,a,<en,b>>))->
    event(a)
    mois(b)
    ;
prep("avant".x,x,localization(a,time,<moment,a,<avant,b>>))->
    event(a)
    temporal-object(b);
prep("avant".x,x,localization(a, order, <position,a,<avant,b>>))->
    sequence(s)
    follows(a,b,s)
    ;
prep("après".x,x,localization(a, time, <moment,a,<apres,b>>))->
    event(a)
    temporal-object(b)
    ;
prep("après ".x,x,localization(a, order, <position,a,<apres,b>>))->
    sequence(s)
    follows(b,a,s)
    ;
noun("pont".x,x,gen(mas).num(sg).initial(consonant).nil,pont)->;
noun("gare".x,x,gen(fem).num(sg).initial(consonant).nil,gare)->;
noun("carrefour".x,x,gen(mas).num(sg).initial(consonant).nil,carrefour)->;
noun("tour".x,x,gen(fem).num(sg).initial(consonant).nil,tour)->;
noun("rencontre".x,x,gen(fem).num(sg).initial(consonant).nil,rencontre)->;
noun("excursion".x,x,gen(fem).num(sg).initial(vowel).nil,excursion)->;
noun("soirée".x,x,gen(fem).num(sg).initial(consonant).nil,soiree)->;
noun("apéritif".x,x,gen(mas).num(sg).initial(vowel).nil,aperitif)->;
det("le".x,x,gen(mas).num(sg).initial(consonant).nil)->;
det("la".x,x,gen(fem).num(sg).initial(consonant).nil)->;
det("l'".x,x,gen(g).num(sg).initial(vowel).nil)->;
nom("lundi".x,x,gen(mas).num(sg).nil,lundi)->;
nom("mardi".x,x,gen(mas).num(sg).nil,mardi)->;
nom("mercredi".x,x,gen(mas).num(sg).nil,mercredi)->;
```

```
nom("jeudi".x,x,gen(mas).num(sg).nil,jeudi)->;
nom("janvier".x,x,gen(mas).num(sg).nil,janvier)->;
nom("février".x,x,gen(mas).num(sg).nil,fevrier)->;
nom("mars".x,x,gen(mas).num(sg).nil,mars)->;
nom("avril".x,x,gen(mas).num(sg).nil,avril)->;
nom("alpha".x,x,gen(mas).num(sg).nil,alpha)->;
nom("beta".x,x,gen(mas).num(sg).nil,beta)->;
nom("gamma".x,x,gen(mas).num(sg).nil,gamma)->;
nom("delta".x,x,gen(mas).num(sg).nil,delta)->;
nom("un".x,x,gen(mas).num(sg).nil,1)->;
nom("deux".x,x,gen(mas).num(sg).nil,2)->;
nom("trois".x,x,gen(mas).num(sg).nil,3)->;
nom("quatre".x,x,gen(mas).num(sg).nil,4)->;
```

NOM is the category of those nominals which occur without a determiner.

```
np(x,y,gen(g).num(n).nil,m)->
    det(x,z,gen(g).num(n).initial(i).nil)
    noun(z,y,gen(g).num(n).initial(i).nil,m)
    ;
np(x,y,f,m)->
    nom(x,y,f,m)
    ;
pp(x,y,localization(a,d,<q,a,<p,b>>))->
    prep(x,z,localization(a,d,<q,a,<p,b>>))
    np(z,y,f,b)
    ;
pp(x,y,localization(a,time,<moment,a,b>))->
    nom(x,y,f,b)
    event(a)
    day(b);

verb("est".x,x,num(sg).nil,localization(a,d,<q,a,<p,b>>))->
    ;
verb("est".x,x,num(sg).nil,localization(a,time,<moment,a,b>))->
    day(b)
    ;
verb("se trouve".x,x,num(sg).nil,localization(a,space,<place,a,<p,b>>))->
    physical-object(a)
    physical-object(b)
    dif(a,b)
    ;
verb("a lieu".x,x,num(sg).nil,localization(a,time,<moment,a,<p,b>>))->
    event(a)
    temporal-object(b)
    ;
verb("a lieu".x,x,num(sg).nil,localization(a,time,<moment,a,b>))->
    day(b)
    ;
verb("a lieu".x,x,num(sg).nil,localization(a,space,<place,a,<p,b>>))->
    event(a)
    physical-object(b)
    ;
vp(x,y,f,localization(a,d,<q,a,b>))->
    verb(x,z,f,localization(a,d,<q,a,b>))
    pp(z,y,localization(a,d,<q,a,b>))
    ;
sentence(x,y,localization(a,d,<q,a,b>))->
    np(x,z,gen(g).num(n).nil,a)
    vp(z,y,num(n).nil,localization(a,d,<q,a,b>));
```

```
"6. Two more easy questions"

what-means(x,m)->
   sentence(x,y,m)
   ;
```

x is a sentence, given as list, whith the lexikon items written within quotes; m is a representation of a meaning. The program is conceived in such a way that nonsensical sentences have no meaning. - The rule not only assigns meaning representations to sentences, but also sentences to meaning representations.

```
just-talk(x)->
   sentence(x,y,m)
   ;
      Here, as above,  x is a sentence. This rule just tests whether a
      given sentence is generated by the program.

;End world: Normal
```

VERBS FOR THE EXPRESSION OF TEMPORAL AND KINETIC SITUATIONS IN NL

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This paper intends to give a brief account of a tentative classification for basic English verbs for the expression of motion and time relations which was carried out following a situational paradigm.[1] Since some new terminological distinctions were used, I will briefly refer to them first.

1. Introduction. Some terminology

In this approach, the basic unit of reference will be called *prototypical situation*. This is considered to be the semantic representation of some sort of event that takes place in reality. In a prototypical situation different elements can be found, the most important being (a) an *entity* E and (b) a property, a quality or a relation of that entity, under the generic term of *predicate* (P). Two predication types can be distinguished: *descriptive* and *performative*. The former "describe" situations, whereas the latter "create" situations (therefore accounting for the concept of "performativity" as stated by Austin and Searle).

In descriptive predications, a description of the reference situation is carried out, with two main types: (a) descriptions of state, and (b) descriptions of change of state. Both of them represent a prototypical situation whose configuration is: $A - P_0 - [E - P_1] = A - P$, where A=Agent (entity), I=Instrument, E=Main entity, P=Predicate ($P=P_0+P_1$), C=Circumstance (manner, time or place). A may appear beside I, and C may be applied to

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[1]This is part of some research carried out on a corpus of 608 "basic" verbs of the English language studied in sentences taken from journals and dictionaries. More details can be found in Inchaurralde (1991a, b, c).

P_0 or P_1.

The main basic situations in this model are the following: existential (we predicate of an entity its existence or non-existence; e.g. "In Moscow there is a growing awareness..."), kinetic (we predicate of an entity its movement from a point x to another point y; e.g. "I went to Stockholm"), possessive (we predicate of an entity its being or not in a possessor-possessed or whole-part relation with another entity; e.g. "The land belongs to a big family"), sensory vital (we predicate of an animate entity its feeling a given positive or negative sensation; e.g. "I enjoyed the holiday enormously"), perceptual (the main entity may be any concrete entity that can be object of perception; of such entity some given perceptual properties are predicated), general functional (it is predicated of a given entity its usefulness or concrete use for a certain activity, from a human perspective; e.g. "... a rifle which will perform satisfactorily under those conditions"), functional vital (we have an animate entity of which we predicate the carrying out of a given vital (necessary for life) function; e.g. "He just woke up"), epistemic (we predicate here the knowledge or lack of knowledge of certain information by a human entity; e.g. "My father knew John very well"), grouping (we predicate the grouping of an entity or entities with another entity or group of entities; e.g. "The two rivers joined"), hiding (it is predicated of an entity its hiding or not hiding; e.g. "He shut himself in his room to think") and argumentative (there is a human entity from which an argumentative action is predicated; e.g. "Gorbachev may not accept the U.S.'s position,..."). We will deal here only with the kinetic and temporal situations. The latter has not been mentioned above because of its less clear status as a situation on its own.

Processes of overlapping, sequencing, derivation and subordination for the creation and delimitation of infinite other situations are also accounted for in the model.[2]

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[2]All this is adequately explained in Inchaurralde (1991a).

2. Kinetic and temporal situations: parameters and spatio-temporal mapping

2.1. The kinetic situation

In the kinetic situation E's movement from a point x to another point y is predicated. This movement can be caused by another entity agent (A).

The parameters x (departure point) and y (arrival point) are important in the kinetic situation. There exist several possibilities, which are generally marked in the surface structure by means of prepositions. Some examples are:

Movement to the left or to the right:

$$y \longleftarrow x \longrightarrow y$$

LEFT   *RIGHT*

Upward or downward movement:

y UP
▲
|
x
|
▼
y DOWN

Inward or outward movement:

$x \longrightarrow y$ *OUT*
$y \longleftarrow x$ *IN*

Apart from the direction of the movement it is important in this type of situation the way in which such movement goes through a given medium. This can also be expressed by means of prepositions such as ACROSS, ALONG, THROUGH, etc.

The circumstance of manner allows here for many possibilities, as can be seen in examples of the corpus used. It is also important to mention that we may focalize the beginning, the development or the end of the movement.

A more complex variant of the kinetic situation takes place when points x and/or y, in turn, move to meet or to separate; also when there exist two underlying kinetic situations, i.e. when the semantic representation includes two or more entities in convergent or divergent movement.

2.1.1. Movement and no movement

(A) Movement

Movement of any entity: *Move* expresses the idea of movement in general. With the help of prepositions and the adequate complements, this verb can express all the possibilities of the kinetic situation. This provides us with expressions such as the following: *move about, move around, move along, move away, move in, move off, move on, move out, move over.*

Other verbs which are representative of the kinetic situation are *come, get* and *go* (e.g.: *"come and look... ", "I went to Stockholm").*

Although the characteristics of the underlying prototypical situation are similar for *come* and *go*, their use depends on the spatial location of points x and y with respect to the illocutionary subject: x ≡ Ls corresponds to *go*, y ≡ Ls corresponds to *come* (Ls = location of the illocutionay subject).

These two verbs also accept various prepositions and complements, allowing many types of movement, provided that there is an identity of x or y with the location of the illocutionary subject.

Finally, we also have other verbs, such as *pass* and *set.*

Beginning of movement of any entity: All the verbs that appear in this section express a movement of E, focalized on its beginning. E starts moving: *go away, go off, leave, set off, set out, start off, start out, get out* (e.g.: *"He had gone off to work").*

End of movement of any entity: Verbs that focalize E's movement at its end. E stops moving. *arrive, come in, descend upon, descend on, enter, get in, get to, reach, turn up, draw up, draw in, pull in, pull up* (e.g.: *"He arrived back at his hotel soon after midnight").*

Movement of any entity downwards: Verbs expressing a movement of an entity E downwards. Apart from the variants with *move, go* and *come,* we also have the following forms: *descend, get down, get off, sink, fall, fall down* (e.g.: *"The ship sank", "She fainted and sank to the ground").*

Movement of any entity upwards: In this section we have verbs expressing a movement of any entity E upwards. Apart from the variants with 'move', 'go' and 'come', there are also the following forms: *climb, get on, arise, get up, pick oneself up, rise, lift* (e.g.: *"This window won't lift").*

Movement of any entity towards the outside with movement towards Ls: Here we have verbs expressing a movement towards the outside from the inside of a closed or non-visible space (there is overlapping with the 'hiding situation'), directed towards the location of the illocutionary subject ($y \equiv$ Ls). Forms: *come out* and *appear* (e.g.: *"Active regions, visible as spots and faculae, appear where these lines intersect the photosphere").*

Movement of inanimate entity towards the outside, with movement from Ls: Expressions dealing with a movement of inanimate entities from the location of the illocutionary subject ($x \equiv$ Ls) towards the outside. This type of situation is also to be interpreted as a variety of the 'grouping situation'. Forms: *draw apart, draw away, draw out, pull out, pull over* (e.g.: *"We watched from the bridge as the train pulled out of the station").*

Movement of human entity towards the outside: Expressions dealing with a movement of human entities towards the outside, such as *break out, escape, fly, get away, avoid, get (a)round, desert, leave, leave behind* (e.g.: *"The prisoner broke free/loose", "I avoided punishment by running away").* As happened in the previous section, this kind of situation is also to be interpreted as a variant of the 'grouping situation'.

Forward movement of any entity: Some verbs which emphasize the fact that E moves forward are *advance, move forward* (e.g.: *"The snake advances smoothly and silently").*

Movement of any entity with change of direction: Verbs expressing a movement with one or several changes of direction. They may also express a deformation caused on entity E by a force which undergoes change of direction (we may talk in this case of a change in existential status in addition to a kinetic situation): *curve, turn, turn off, turn on, bend, lean, shake, swing, spin, twist, wind* (e.g.: *"The wheel turned slowly"*, *"The branch bent"*, *"The explosion shook the house: the house shook"*, *"The door swung shut"*, *"The road curved to the right"*, etc.).

Fast movement of a human entity: We may include here motion verbs for human entities in which there is a restriction in the way the movement is carried out (it is fast): *hasten, hurry, rush, rush into, rush in, shoot* (e.g.: *"He hastened home"*, *"Don't hurry; we're not late"*, *"He shot his way out of prison").*

Movement of different kinds of entities with variations in the medium (not overland) through which this movement takes place: There are here verbs expressing the idea of movement through some given medium (water, air, etc.). This can take place with the help of a vehicle (entity instrument I): *fly, ride, sail, drive* (e.g.: *"to drive a car"*, *"This car drives easily").*

It can also be carried out without the help of any vehicle: *fly, swim, float* (e.g.: *"Clouds were flying across the sky").*

Movement of human entities overland: Essentially, this kind of situation can be seen with verbs indicating "ways of walking". *cross, roll, run, step, walk, wander, march, stamp* (e.g.: *"Cross the river at this point").*

Movement of animate entity towards mobile target which in turn moves to another place: This situation is expressed by means of verbs 'of persecution'. We may talk here of two overlapping kinetic situations. E1's goal in the main situation is E2, the latter being the main entity in the secondary situation. This second entity has a goal which is even farther away from E1. The expression representing E1 functions syntactically as subject and that representing E2 as direct object. Verbs: *chase, follow, go after, hunt* (e.g.: *"The police are hunting the murderer").*

Movement of human entity towards mobile human entity approaching it: There are again two human entities which meet (that is why this situation may also be considered to be a variety of the 'grouping situation'. E2 approaches E1, and this first entity in many cases approaches E2. The expression representing E1 functions syntactically as subject and that representing E2 functions as direct object. Verbs: *greet, meet, receive, welcome* (e.g.: *"George Bush will be receiving a Soviet leader who has openly warned that his country may be heading toward civil war").*

Caused movement of different kinds of entities with variations in the circumstance of manner: We have here many possibilities, since there are many possible variations in the circumstance of manner. Verbs: *beat, shake, tremble, wave, hang, lower, scatter, throw* (e.g.: *"The bird's wings began to beat").*

(B) No movement

End of movement (beginning of no movement) of any entity: The most characteristic verb to signal the end of any movement is *stop* (e.g.: *"The rain has stopped").*

End of movement (beginning of no movement) of inanimate entity: Some of these verbs have restrictions as to what situation they can represent. We have here *come alongside, drop anchor, put in, tie up, land, take off* (e.g.: *"His plane lands at six thirty").*

No movement of animate entity up to a new situation, in which a new movement will begin: We may include here verbs which have to do with the 'wait' situation (derivation from the kinetic situation), in which there is a temporal suspension of movement, and a disposition to start it over again as soon as other circumstances allow it. Some verbs are *wait, remain, stay, attend* (e.g.: *"I'm waiting for John to come").*

2.1.2. Caused movement and no movement

(A) Caused movement

Caused movement of any entity: We have here again a verb expressing the general idea of movement, *move* (e.g.: *"Please move your car; it's blocking my way out"*). When this movement is caused, its use is transitive, the expression corresponding to A being the subject and the expression corresponding to E the direct object. Other forms of this verb are the following: *move about, move around, move along, move away, move in, move off, move on, move out, move over.*

Caused downward movement of any entity: We shall mention here the verbs expressing downward movement of any entity that are used transitively: *sink* (*"The lack of money will certainly sink our plans"*).

Caused upward movement of any entity: We have here the verbs expressing upward movement of any entity that are used transitively: *get on, get up, raise* (e.g.: *"He raised his eyebrows in extravagant surprise").*

Upward movement of any entity caused by animate entity: Two characteristic verbs are *lift, raise* (e.g.: *"The baby was lifted onto the bed", "He raised the fallen child to its feet").*

Downward movement of any entity caused by animate entity: Representative expressions are *let down, lower, dip, drop, let fall, let go* (e.g.: *"He dropped the gun").*

Caused forward movement of any entity: We have here some verbs which emphasize the fact that movement is forward *advance, move forward.* In this case, their use is transitive (e.g.: *"Close the camera and advance the film with the winder")..*

Inward movement of any entity caused by human entity: Verbal forms representative of this situation are *get in, put in* (e.g.: *"Sewerage facilities would be put in... ").*

Outward movement of any entity caused (mainly) by animate entity: *get out, have out, remove, take out, send away, send off, take away, give off, throw away, throw out* (e.g.: *"He took the book out of the parcel").*

Inward movement of animate entity allowed by human entity: In this kind of situation, the movement of E inwards comes with permission from a human entity A, which in this way contributes to its realization. Interpreted from a logical perspective, these predicates use deontic operators. Verbs: *admit, let in* (e.g.: *"Let the cat in, will you?").*

Outward movement of animate entity allowed by human entity: As in the previous case, the movement of E (which is now outward movement) takes place because the human entity A allows it. Again, from a logical perspective, these predicates use deontic operators. A characteristic expression would be *let out* (e.g.: *"The other prisoners were locked into their cells before I was let out of mine").*

Movement of any entity caused by another entity (human in many cases) towards a destination where it will stay fixed: The verbs that follow express a movement of any entity E, caused by an entity A (which is human in most cases) towards a destination where it will stay fixed, without any further movement afterwards: *fit, fix, place, put, set, lay* (e.g.: *"to fix the door open", "A bricklayer is a man who lays bricks").*

Movement of any entity caused by another entity, which accompanies it during all its traject: In this case, the entity A produces the movement of E accompanying it throughout all its traject up to its destination. Three representative verbs are *take, bring, carry.*

As it happened with *come* and *go*, *bring* and *take* are used according to the coincidence of x and y with Ls. If $x \equiv$ Ls, *take* will then be used. If $y \equiv$ Ls, *bring* should be used. *Carry* is used in any of the two cases.(e.g.: *"Take him another cup of tea", "I was* *carrying in these guitar cases..."*).

Other possibilities are: *deliver, bear, lift, send, guide, lead, direct, show, drag, draw, pull, push, draw out, pull out, pull back, stick*, etc. (e.g.: *"Typically, it is delivered by injection into a muscle or under the skin"*, *"The baby was lifted onto the bed"*, *"to lead an expedition"*, *"May I show you to your seat?"*).

Caused movement of any entity with change of direction: We have here different verbs expressing a movement with a change of direction. They can also express a deformation in the entity E caused by the change of direction of a force that is applied (in this case, we are talking of a change in existential status, and there is more than just a kinetic situation). Verbs: *turn, turn off, turn on, bend, lean, shake, swing, curl, spin, twist, wind* (e.g.: *"The police turned their guns on the bank robbers as they ran away"*, *"to bend one's head in worship"*, *"The two men shook hands"*, *"He was swinging his arms"*).

Caused fast movement of human entity: *Hasten, hurry, rush, rush into, rush in* (e.g.: *"He hastened his steps"*, *"Don't hurry me"*).

Caused movement of different kinds of entities with variations in the medium (not overland) through which movement takes place: Characteristic verbs are *fly, ride, sail, drive, float* (e.g.: *"to drive a car"*, *"He flew the plane well"*).

Caused movement of different kinds of entities with variations in the circumstance of manner: We have here the transitive uses of verbs which also express different possibilities of movement, according to the circumstance of manner. Forms: *beat, shake, remble, wave, hang, lower, scatter, throw* (e.g.: *"to beat the door down"*, *"Hang your coat (up) on the hook"*, *"He scatters money about as if he were rich"*, *"He threw the ball 100 metres"*).

(B) Caused non-movement

Caused end of movement (beginning of non-movement) of any entity: The most characteristic verb for the expression of the end of a movement is *stop* (e.g.: *"You're trying to stop my trip to London")*.

2.2. The passage of time

2.2.1. Simple temporal situation

The main entity E may be either a whole situation temporally determined or an entity inside this situation, whose corresponding expression is the subject. Some examples are

Stop in time: *pause* (e.g.: *"He paused and then went on in a low voice")*.

Temporal movement (passage of time): *Pass, continue, go by, go on, last, spend* (e.g.: *"More than two centuries passed between the first European sunspot observations")*.

Start: *begin, start, break out, bring in, burst into, set forth, set in, set off, set out, set up, start off, start up* (e.g.: *"We started at six")*.

End: *Cease, close, close down, close up, end, finish, shut, shut down, shut up, stop, break down, dry up, give up, pack up, run out, wear off, wear out, complete, finish up, land up* (e.g.: *"I'll have to stop in tonight")*.

Time "freezes": *Delay, hold back, hold up* (e.g.: *"They're trying to delay until help arrives")*.

2.2.2. Caused temporal situation

The expression for the entity agent A -which gives rise to the temporal situation- usually functions as the subject of the sentence involved. The expression for the entity E, the situation -or main entity within that situation- affected by temporal circumstances, usually functions as direct object.

Caused stop in time: *Stop*.

Caused start in time: *Begin, start, introduce, break out, bring in, set in, set off, set out, set* *up, start off, start up* (e.g.: *"He gave it a push and started it going")*.

Caused end in time: *Cease, close, close down, close up, end, finish, shut down, shut up, stop, break down, dry up, pack up, wear off, wear out, complete, finish up, land up* (e.g.: *"We stopped the fight")*.

Caused "freezing" of time: *Delay, hold back, hold up* (e.g.: *"What delayed you so long?")*.

Caused postponement in time: *Put off* (e.g.: *"They kept putting off signing the paper")*.

3. Space-time parameters: correspondences. Conclusion

It has been suggested that space and time relations can be analysed using similar parameters. The fact that space concepts can substitute for time concepts is clearly seen in the large amount of spatial metaphors used for expressing time (cf. Lakoff, 1990: 55 ff.). Interestingly, there seems to exist not only a physical, but also a linguistic -or rather conceptual- space-time. As far as the classification I am talking about is concerned, there are several notions that can be used for parametrization of both space and time: length (duration). path, interruption, location, start point, end point, limit, anteriority, posteriority, etc. Calbris (1985: 43-46) shows many examples of prepositions, verbs and adverbs in French expressing these notions both spatially and temporally.

Accordingly, the kinetic and temporal situations I have just talked about may be parametrized in a similar way. Motion deals with changes of spatial relations in time, and therefore has a strong spatial component. On the other hand, the passage of time emphasizes pure time relations.

We can set up the following table of correspondences:

KINETIC	PASSAGE OF TIME
length of traject	duration
actual path	factual time (vs. hypothetic)
stop	interruption

spatial location	temporal location
source	start
goal	end
limit	
spatial anteriority	anteriority in time (order relation)
spatial posteriority	posteriority in time (" ")

Due to the dual quality of motion (it deals with SPACE in TIME), not only do the spatial notions on the first column have to be considered, but also those on the second column. It is therefore convenient to assume that in many instances of the kinetic situation the passage of time is expressed and also presupposed. This makes it possible to refer to motion through verbs that normally emphasize the passage of time (e.g. *"The journey from Paris to San Francisco was completed")*. Conversely, the flow of time can be expressed through motion verbs (e.g. *"Time will fly from now on")*. This completes the picture, showing that the classification outlined above is not rigidly organized into closed sets. In fact, a given verb can express many different situations, according to the complements it uses, and guided by contextual clues. Since this paper has intended to be simply a descriptive account of a tentative classification for verbs, and due to space limitations, this question will not be considered further. As for the classification, it is still incomplete and provisional, especially if we take into account the fact that it is based on a list of "basic" verbs and a limited corpus of examples. However, I think it has been shown that a situational paradigm used in this way may become a useful instrument in organizing this kind of data.

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A unified processing of orientation for internal and external localization

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1- Introduction

This work on orientation comes within the framework of a more general research project which aims at giving a formal representation of several linguistic markers' semantic content. In the category of referents, this project deals with French Internal Localization Nouns (henceforth ILN) such as *haut* (top), *avant* (front), *intérieur* (inside), *bord* (edge) which are all lexical elements pointing out the different portions of an object. As for the spatial relations, we consider internal and external prepositions (*sur* (on), *dans* (in)/*devant* (in front of), *au-dessus de* (above), etc.) as well as several verbs of movement (*se diriger vers* (to go towards), *venir de* (to come from), *passer par* (to pass through)).

A semantic analysis of these lexemes has been carried out by means of which it has been possible to bring to the fore some important properties of spatial structures in language (Borillo A. 88). On the basis of these observations, a formal system for the representation of spatial entities and relations has been proposed which is made up of three levels encoding respectively geometrical, functional and pragmatic data.

It can be underlined that orientation plays a great part in the semantics of most of these ILNs as well as in the semantics of prepositions such as *sur* (on), *au-dessus de* (above), *derrière* (behind), etc. (that is to say in both referent and relation categories and in both internal and external cases). We present in this paper a formal treatment of orientation which improves, on various aspects, a previous formalization we gave in (Aurnague 91) to represent this important feature of spatial semantics. This new formal tool which tries to better grasp the differences between deictic and intrinsic orientation can be used to handle both internal and external localization (*le haut* (the top)/ *au-dessus de* (above), *l'avant* (the front)/*devant* (in front of), etc.).

Here, we follow the methodological choices that have been defined for the whole research project. From an empirical point of view, the study has been grounded on a detailed and systematic linguistic analysis which must highlight and classify the different meanings of each lexeme, in particular, the distinct spatial configurations it refers to. The second point concerns the elaborated formalisms which, beyond the representation of the semantic content, should have adequate inferential properties. More precisely, we want to be able to use the formal representations we build in order to draw inferences whose results have to be in accordance with the results of natural reasoning made by human beings.

In this paper, we will first recall the main characteristics of the overall representation system of spatial expressions' semantics already proposed, focusing on the orientational part. We will then introduce new tools for dealing with orientation in internal and external localization processes.

2- A 3 level system for the representation of space in language

This section is a summary of what is presented in (Aurnague & Vieu in press). Contrary to (Leech 69) and to a certain extent to (Miller & Johnson-Laird 76), Vandeloise showed in (Vandeloise 86) that a purely geometrical representation of the semantics of spatial prepositions is not appropriate. For instance, if *sur* (on) was represented only with the relation of contact, we could not make the difference between the sentences:

La tapisserie est sur le mur
(The wall-paper is on the wall)
L'armoire est contre le mur
(The cupboard is against the wall)

In this example, the geometrical approach does not take into account the functional component of the semantics of the preposition *sur* (on) corresponding to the notion of "support". More generally, the functional aspects of the relations and entities involved in spatial expressions play a major part in the semantics of spatial markers. However, we do not claim, as Vandeloise, that functional notions alone can fully explain spatial semantics and we think that geometrical and functional data have to be articulated.

As in any field of NL, pragmatic phenomena influence the semantics of spatial markers. For instance, a book is usually said to be *on the table* even though the book is on another book, thus not in contact with the table. Because the relation between the two books is not relevant, one can "forget" about it and put the book directly in relation to the table. In (Herskovits 85), A. Herskovits shows that, if instead of two books one on top of the other, it was a lid on a tea-pot, it would be impossible to "infer" that the lid is on the table. In this case, being on the tea-pot, the lid fulfills its function with respect to the tea-pot and this fact cannot be "forgotten". Several pragmatic principles can be isolated which are in fact instances of more general ones that rule any kind of discourse or dialogue, as Grice's principles of cooperativity (Grice 75). For instance, the underlying pragmatic principles involved in the previous example are the maxims of relevance and quantity. If a fact is relevant (in this case *the lid is on the pot*) for expressing a less precise fact (in this case *the lid in on the table*) somehow implies that the precise fact is not verified in the given situation.

According to these remarks and to several others of the same kind we have proposed to represent the meaning of spatial expressions by means of a three level system which takes into account respectively geometrical, functional and pragmatic information.

2.1- The geometrical level

On the geometrical level, we deal with the topological notions of inclusion, contact, boundary..., and with concepts related to projective geometry such as straight line, distance, order on a straight line, etc.

On this level, we handle the spatial referents of the entities, that is, the space portions determined by their matter at a determined moment. These elements are also called here individuals.

The actual use of prepositions like *sur* (on) and *dans* (in) which allow us to situate an entity called trajector with respect to another entity called landmark shows the relational nature of the structures handled in the language as opposed to the absolute spaces used in robotics (where entities are localized by means of coordinates). In order to reflect these characteristics, topological data is represented in our system by means of B.L. Clarke's individual calculus (Clarke 81) that we have modified and completed so as to take into account some important spatial concepts in language. This calculus, which is based on the sole primitive relation of connection between two individuals (c(X,Y)), is used to define some mereological operators as well as Boolean and topological ones.

As regards mereology, we can mention inclusion, overlapping and external connection between two individuals. In the Boolean part of the calculus, the operators sum, product and complement are introduced. As for topological aspects, the interior of an individual, its closure and the properties of being closed and open can be defined.

The individual calculus based on connection is not sufficient, as it is, to deal with some problems related to the semantics of space in language. Consequently, we have extended this theory in order to express some fundamental spatial notions such as limits, contact, etc. We have introduced three types of limit relations (lim1, lim2, lim3) through which surface-, line- or point-like individuals can be differentiated. These limit concepts are very important for the formalization of ILNs like *dessus* (top extremity), *bord* (edge), *angle* (corner), etc. (Aurnague 91). We also added to the strong contact represented by external connection (the individuals in contact are assumed to share part of their boundaries) a notion of weak contact (the individuals are not connected although they are touching together) which seems to better match common sense. Let us indicate that contact plays a great role in the semantics of the relation *sur* (on).

As already mentioned, on the geometrical level, we do not only take into account topological data but we also integrate some important concepts of projective geometry.
Having defined "points" in this theory as sets of two by two connected individuals (maximal filters), we specified the notions of straight lines, oriented straight lines, through various definitions based on the primitive relation (linking points) "is situated between". We have also introduced distance by means of the primitive relation "is closer to" and this relation, together with the other one, makes it possible to define concepts of parallelism and perpendicularity. We associate a system of abstract (no oriented) axes and directions with the spatial referent of every entity and we locate the different portions with respect to the whole entity by "projecting" them on these axes. We can conclude the presentation of this level by saying that we obtained a complete relational geometry.

2.2- The functional level

At this level, we deal with properties linked to the entities themselves and therefore we handle variables representing entities and not mere pieces of space. Above all we have to make it clear that an important assumption of our study is based on the delimitations of the universe of spatial entities we describe and process (essentially with respect to their shape). So, at least for the analysis of ILNs, we restrict the research field to solid, undeformable and connected objects that also have a normal usefulness. We deal with a class of entities whose shape is roughly parallelepipedic, cylindrical or spherical. Moreover, we consider utterances which are "instantaneous" in the sense that neither the entities described nor the speaker change their relative positions.

One of the most important processes which takes place on the functional level concerns orientation. As stated before, only abstract directions are handled in the geometrical module. The orientation process, which is greatly conditioned by functional features, consists in mapping an abstract orientation onto a concrete one.

Apart from the notion of orientation, we introduce on the functional level some concepts belonging to "naive physics" (Hayes 85) such as support and containment. As shown in section 2, support is essential in *sur*'s semantics: an object hanging above a table, touching it, is not *sur la table* (on the table). Containment which plays a great part in the determination of natural inside can be described as the restriction of some potential movements of the contents.

On this level, we distinguish three types of entities: the objects (all the examples given above concern them), the locations (countries, cities, gardens...) and the non-material "space portions" (as insides of objects, holes, cracks...). Using those categories and a lattice structure for representing plural entities, we define 6 types of part-whole relations which play a great part in some uses of *dans* (in) (Vieu 91).

Thanks to these tools we introduce some formal definitions for the lexemes we study, that is to say, for 10 ILNs as well as for the prepositions *sur* (on) and *dans* (in). According to our methodological choices, we check whether the definitions we give in our system allow inferences in accordance with natural "deductions".

2.3- The pragmatic level

Some pragmatic principles act on the semantics obtained at the previous levels in a significant way. On top of functional knowledge, they use world knowledge (in particular, knowledge of typical situations) and information about context. The principles we consider here may be seen as the instanciation of more general ones (such as Gricean cooperativity principles (Grice 75)) in the spatial domain.

First, pragmatic principles lead to deduce, in some cases, more information than is really present in the text and is represented on the first two levels (so we need a non-monotonic logic on this level). For instance, the sentence *Marie est dans la voiture* (Mary is in the car) is generally understood as *Mary is in the passenger space*, discarding at the same time the alternative *Mary is in the boot.*

Second, they may rule out some expressions (for example, expressions inferred at the previous levels) because, even though their "crude" semantics is verified by the system and in the model, they cannot be uttered, since using the first process mentioned, these expressions would be regarded as conveying information contradictory with what is known. For instance, if we know that *Marie est dans le coffre de la voiture* 'Mary is in the car's boot' is true, then *Marie est dans la voiture* 'Mary is in the car' is not false, and yet, in general we cannot answer to *where is Mary?* with the latter sentence, for in most contexts, it is interpreted as *Mary is in the passenger space.*

A "fixation principle" underlies the examples cited above. This principle, first introduced in (Vandeloise 86) expresses that the typical use of an object "fixes" some of its characteristics. For instance, the front and the back of a car are "fixed" by the usual —not the actual— direction of its motion; indeed, many intrinsic orientations are determined this way. Several other principles may be found.

Third, we must mention the pragmatic phenomenon that enables us to loosen some conditions of the semantic definitions. This phenomenon has been illustrated in the previous example of the books on the table in which was involved the maxim of relevance.

2.4- Focus on orientation

Let us go back to the way the orientational process was defined in the formal system we presented up to now. We said that the spatial referent of every entity has a system of abstract orthogonal axis associated with it and, as we will see, this is not a very accurate representation of what really takes place.

In fact, a detailed study of orientation shows that an intrinsic orientation follows from the internal properties of an entity, in particular its shape but also its function. Consequently, the axes or straight lines arising in such an intrinsic orientation are linked to the entity itself and not just to its spatial referent. In the case of a contextual process, the orientation is the result of the interaction between the entity concerned and another entity in the context. This means that the relevant axes in a contextual orientation derive from the interaction between these two entities. In the framework of this study, we only consider a particular case of contextual orientation, namely the deictic one, in which the orienting entity is the speaker.

So, if we wanted to give a very accurate account of the orientational process as it really occurs, we would have to associate predefined axes only to intrinsically oriented entities, whereas for a deictic orientation the axes would be defined taking into account the interaction between the oriented entity and the speaker.

However, this is not the case in the formalism already proposed and even though we could calculate whether we are faced with a deictic or intrinsic case, from the point of view of the axes' construction, there is no difference between intrinsic and deictic orientation.

According to these remarks, our new orientation formalism has to fulfill two main points. First of all, it has to grasp how the axes derive from the function of the entities and the shape of their spatial referents. Concerning this point, it can be underlined that giving an intrinsic orientation to an entity in a determined direction amounts to say that for "functional reasons" a particular portion of this entity constitutes an extremity in this direction (e.g.: usually the neck of a bottle is up).

A second requirement for the new formalism relies on the necessity of using the same orientational tool for internal localization (ILNs) as well as for external one (e.g.: *devant* (in front of), *derrière* (behind), *dessus* (above), *dessous* (below))[1].

The main reason for such a requirement is that, from an inferential point of view, we want to

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[1]A preliminary study and formalization of external relations have been made 3 years ago in our group by N. Hathout (Hathout 89) which is akin on various points to the new formal tool we propose.

be able to combine formal definitions of external and internal markers and to make calculus from these combinations. Another reason would be that, from linguistic and psychologic points of view, the orientational mechanisms involved in internal and external localization seem to be very similar.

3- Analysis and formalization of orientational process

Having presented the main characteristics of our system for the representation of spatial entities and relations, we are going to set out the new tools we introduce in order to deal with orientation. We will detail the formalism at each level of the system.

3.1- The geometrical level

At the geometrical level we complete our ontology by introducing the basic concept of direction. This notion has been already used in various works in the field of Qualitative Physics (Davis 89) or in semantic studies intended for example to handle the spatial information contained in car crash reports (Jayez 92).

A direction is viewed here as a primitive element which can be linked to points by the following axiom, $d(\alpha,\beta)$ being a new primitive function giving the direction determined by two points α and β:

$\forall\alpha,\beta\ (PT(\alpha) \wedge PT(\beta) \wedge \neg DN(\alpha,\beta)) \Rightarrow \exists D\ d(\alpha,\beta)=D$

Another axiom indicates that opposed directions are associated with symmetric ordered pairs of points:

$\forall\alpha,\beta\ (PT(\alpha) \wedge PT(\beta)) \Rightarrow (d(\alpha,\beta)=D \Leftrightarrow d(\beta,\alpha)=-D)$

As we mentioned earlier, a definition of the straight line notion in terms of the relation $T(\alpha,\beta,\gamma)$ which means "α is situated between β and γ" is available in the system[2] (Vieu 91):

$droite(\Delta) \equiv_{def} \Delta \subset V \wedge \exists\alpha,\beta\ (\alpha\in\Delta \wedge \beta\in\Delta \wedge \neg DN(\alpha,\beta)) \wedge \forall\alpha,\beta,\gamma\ ((\alpha\in\Delta \wedge \beta\in\Delta \wedge \neg DN(\alpha,\beta) \wedge \neg DN(\alpha,\gamma) \wedge \neg DN(\beta,\gamma)) \Rightarrow (T(\alpha,\beta,\gamma) \vee T(\beta,\alpha,\gamma) \vee T(\gamma,\alpha,\beta))) \wedge maximal(\Delta)$

This rule states that Δ, subset of the total set of points V containing at least two points, constitutes a straight line if every triplet of points belonging to Δ is such that one of the points is situated between the other two ($DN(\alpha,\beta)$ means "α and β are at a null distance").

Two straight lines $\Delta1$ and $\Delta2$ are orthogonal if there exist two points in each of these straight lines such that the points of the latter are situated at an equal distance from the points of the former (Vieu 91) (the property of equidistance E appearing here is defined from the relation between points "is closer to") :

$per(\Delta1,\Delta2) \equiv_{def} droite(\Delta1) \wedge droite(\Delta2) \wedge \exists\alpha,\beta,\gamma,\delta\ (\alpha\in\Delta1 \wedge \beta\in\Delta1 \wedge \neg DN(\alpha,\beta) \wedge \gamma\in\Delta2 \wedge \delta\in\Delta2 \wedge \neg DN(\gamma,\delta) \wedge E(\gamma,\alpha,\beta) \wedge E(\delta,\alpha,\beta))$

Then, we specify the orthogonality between two directions using these definitions of straight lines and perpendicular straight lines:

$ortho(D,D') \equiv_{def} \exists\Delta1,\Delta2,\alpha1,\beta1,\alpha2,\beta2\ droite(\Delta1) \wedge droite(\Delta2) \wedge per(\Delta1,\Delta2) \wedge \alpha1\in\Delta1 \wedge \beta1\in\Delta1 \wedge \alpha2\in\Delta2 \wedge \beta2\in\Delta2 \wedge ((d(\alpha1,\beta1)=D \vee d(\alpha1,\beta1)=-D) \wedge (d(\alpha2,\beta2)=D' \vee d(\alpha2,\beta2)=-D'))$

In consequence, two directions are called orthogonal if two perpendicular straight lines

[2]In fact, it is also possible to define the membership of a point to a straight line from a point and a direction. Then, a special axiom links the concept of direction to the relation "between" so as to make calculations involving both kinds of constructs possible.

supporting them can be found.

To formalize correctly the orientational process, we also have to introduce at the geometrical level a set of thirteen predicates constituting an extension of Allen's relations (R) (Allen 84). Each relation R(X,Y,D) indicates the configuration holding between the maximum intervals filled by the individuals X and Y in the direction D[3]. Besides the classical axioms related to Allen's relations we introduce here a postulate stating that for every pair of connected individuals X and Y and every direction D, one of the relations m, o, s, d ,f or = stands between them :

$\forall X,Y,D\ c(X,Y) \Rightarrow mosdf{=}m_i o_i s_i d_i f_i(X,Y,D)$[4]

We mentioned earlier that giving an intrinsic orientation to an entity (in a particular direction) amounts pointing out a portion of that entity as an extremity in the concerned direction (when the entity is canonically used). Consequently, the extremity of an individual in a direction seems to be an important notion to grasp in order to formalize intrinsic orientation.

We state that Y is an extremity of X in a direction D if Y is a limit of X (as underlined above the concept of limit has been already formalized at the geometrical level of our representation system) and furthermore if every element included in X (and not included in Y) precedes or meets Y in this direction D:

$ext(Y,X,D) \equiv_{def} lim1(Y,X) \wedge \forall V\ ((p(V,X) \wedge \neg p(V,Y)) \Rightarrow {<}m(V,Y,D))$

It can be observed that, in some cases, for two given elements X and Y (for instance when we are faced with the vertex Y of a triangle X) several directions may verify this relation. Generally, this occurs when a tangent to the surface cannot be associated with some particular point.

If we wanted a unique direction to be selected, we would have to introduce more constraints or conditions. That is exactly what we do by introducing a relation "exts" which indicates that Y is an extremity of X in the direction D and Z an extremity (of a part U of X) in the opposed direction :

$exts(Y,Z,X,D) \equiv_{def} ext(Y,X,D) \wedge \exists U\ (p(U,X) \wedge p(Y,U) \wedge ext(Z,U,-D) \wedge saillant(Z,X) \wedge (\neg\exists V\ point(Y,V) \vee \neg\exists V\ point(Z,V)))$

In this definition the predicate "saillant" accounts for the visual and cognitive processes which lead us to select a geometrically salient element Z in the individual X. A specification of this phenomenon should make a precise study of the underlying processes necessary. The remainder of the definition ensures that this element Z constitutes an extremity in the direction -D and that one of the two extremities is not punctual.

Going back to the case of the triangle, such an additional condition allows us (by taking into account the direction orthogonal to the basis of the triangle) to select a unique direction among the first set of directions.

3.2- Functional level

3.2.1- Intrinsic orientation

Using the different tools we have built up to now at the geometrical level, and taking into account the properties of the entities themselves, we can tackle the formalization of the

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[3]The constraint of spatial connectedness on the studied entities ensures that the extension along a given direction is an interval. Moreover, one may feel necessary to fully express these relations in terms of projections of the individuals onto a straight line and of calculations on the resulting intervals (as usually with Allen's relations). Previously we had in our system a predicate of projection together with several axioms specifying its behavior. However, this predicate has not been used here because it would have implied manipulating "abstract" straight lines, points and intervals not having the same status than what we have defined up to now. We think that such a specification requires a preliminary study of the cognitive processes underlying these operations.

[4]On the basis of this postulate and using the definition of inclusion (relation p of Clarke) as well as several theorems related to Allen's relations it can be proved for instance that :

$\forall X,Y,D\ p(X,Y) \Rightarrow sf{=}s_i f_i(X,Y,D)$

orientational process, considering first the intrinsic case (we only examine vertical and frontal orientation leaving aside for this paper the lateral case).

Basing our analysis on the remark we made about the importance of the extremity notion for intrinsic orientation, we introduce a new partial function mapping an extremity Y of an entity X (and an extremity Z of a portion of X) on the corresponding direction D:

$\forall$X,Y,Z,D dir-ext(Y,Z,X)=D $\Leftrightarrow$ (part(Y,X) $\wedge$ part(Z,X) $\wedge$ exts(stref(Y),stref(Z),stref(X),D))

Henceforth we will say that such a direction is generated by the extremities Y and Z of X.

The above rule which handles directly entities and not simple portions of space (the function stref gives us the portion of space-time filled by an entity; as a result of the instantaneity constraint previously mentioned, this portion corresponds here to a specific temporal slice) relies on the geometrical relation "exts" (indicating that the individual stref(Y) constitutes an extremity of stref(X) in a direction) as well as on the part-whole relations already defined in our system.

Starting on with the vertical intrinsic orientation, a particular direction of an entity can be considered as its upper intrinsic direction if, in a canonical position, this direction coincides with the gravitational upper direction. We express these conditions by means of the following definition[5]:

orient-haut(D,X) $\equiv_{def}$ $\exists$Y,Z (dir-ext(Y,Z,X)=D $\wedge$ ucan(X) $\wedge$ (usage(X) > dir-ext(Y,Z,X)=haut-grav))

In this definition, the predicate "ucan" ensures that the entity X has a canonical use. The use of a non-monotonic implication (> denoting an implicature) allows us to express the coincidence of the directions during a "normal" (canonical) use or functioning of X. We think that the non-monotonic logic proposed in (Asher & Morreau 91) could be a good framework for handling such information.

A similar formula specifies what is a lower intrinsic orientation, and a biconditional links it to the previous upper orientation :

orient-bas(D,X) $\equiv_{def}$ $\exists$Y,Z (dir-ext(Y,Z,X)=D $\wedge$ ucan(X) $\wedge$ (usage(X) > dir-ext(Y,Z,X)=bas-grav))

$\forall$X,D orient-haut(D,X) $\Leftrightarrow$ orient-bas(-D,X)

The processing of frontal orientation calls for more complex mechanisms which mirror more complex phenomena. We distinguish three cases which, as we will see, are not mutually exclusive.

The first case occurs when the frontal orientation of an entity X follows from what Vandeloise calls the "general orientation" of X (Vandeloise 86) which depends on various factors such as the direction of motion, the disposition of perception apparatus, etc. So, we first state that a given direction of an entity X can be considered as a front direction of type 1 if that direction of X coincides with its general orientation:

orient-avant1(D,X) $\equiv_{def}$ $\exists$Y,Z dir-ext(Y,Z,X)=D $\wedge$ orient-gen(X,D)

We find in this category human beings, animals, arrows but also cars and vehicles in general[6].

The second kind of frontal orientation covers all the entities which, in a canonical use, have their frontal direction coinciding with the frontal direction of the user. So, by means of this second rule, we state that a specific direction of an entity X constitutes a front direction of type 2 if the front direction of every entity using X in a canonical way coincides with this direction of

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[5]We indicated earlier that, in the framework of this work, we consider only "instantaneous" utterances. However, the properties of intrinsic orientation we define here concern the whole life of the entity (or at least a significant part of it) and therefore they must have a spatio-temporal reading. We are at the moment working on a temporal translation of such definitions in which directions should be also considered as extended over time (like the other spatio-temporal individuals). TPS(Γ,Y) denoting the set Γ of instants associated to an individual Y and Y/τ representing a slice of Y which corresponds to the instant τ, a spatio-temporal version of "orient-haut" should be: orient-haut(D,X) $\equiv_{def}$ $\exists$Y,Z dir-ext(Y,Z,X)=D $\wedge$ ucan(X) $\wedge$ $\forall\Gamma,\tau$ ((TPS(Γ,stref(X)) $\wedge$ $\tau\in\Gamma$) => (usage(X,τ) > dir-ext(Y,Z,X)/τ=haut-grav/τ))

[6]But not a mere bullet which can only take a contextual orientation.

X:

orient-avant2(D,X) $\equiv_{def} \exists$Y,Z (dir-ext(Y,Z,X)=D $\wedge$ ucan(X) $\wedge$ $\forall$U,V,D' ((utilise(X,V) $\wedge$ avant-i(U,V,D')) > D'=dir-ext(Y,Z,X)))

This second case of frontal orientation that we call tandem orientation happens with chairs, cars, clothes, etc.

The third and last rule corresponds to the entities which, in a canonical use, have their frontal direction opposed to the user's frontal direction (cupboards, computers, TVs, etc.):

orient-avant3(D,X) $\equiv_{def} \exists$Y,Z (dir-ext(Y,Z,X)=D $\wedge$ ucan(X) $\wedge$ $\forall$U,V,D' ((utilise(X,V) $\wedge$ avant-i(U,V,D')) > D'=-dir-ext(Y,Z,X)))

Finally, we express with the following axioms that every entity having an intrinsic frontal orientation falls into one of these three cases and that front and back (intrinsic) directions stand in a relation of opposition :

orient-avant(D,X) $\equiv_{def}$ orient-avant1(D,X) $\vee$ orient-avant2(D,X) $\vee$ orient-avant3(D,X)

$\forall$X,D orient-avant(D,X) $\Leftrightarrow$ orient-arriere(-D,X)

The lateral cases formalization is not completely worked out and we leave it aside for the moment. However, it can be underlined that this lateral modality calls for already more complex representations than frontal orientation does (which, as we just saw is itself more complex than the vertical one). This property of our formal tools seems to match perfectly the observations made by psycholinguists about acquisition and manipulation of orientation notions.

3.2.2- Definitions

Thanks to all of the geometrical and functional tools introduced above, we can now express the "crude" semantics of various internal and external localization lexemes. We will especially consider the formalization of their semantic component relative to orientation.

3.2.2.1- Internal localization

Let us start with Internal Localization Nouns (ILNs) and more precisely with the definition of the *haut* (top) of an entity. Intuitively, the intrinsic top corresponds to the portion of the entity situated in the pole whose direction is the intrinsic upper direction. In consequence we state by means of the following definition, that an entity Y constitutes the intrinsic top of an entity X if Y is the maximal element situated in the pole of X whose direction is D and furthermore if this direction corresponds to the intrinsic upper direction of X:

haut-i(Y,X,D) $\equiv_{def}$ orient-haut(D,X) $\wedge$ ds-pôle(Y,X,D) $\wedge$ $\forall$W (ds-pôle(W,X,D) => part(W,Y))

The direction appearing in this predicate *haut* plays a very important part for the distinction between intrinsic and deictic top cases. In the case of an intrinsic top this direction comes from the entity itself whereas in a deictic situation it is given by another element of the context (the speaker) and does not have any special relation with the entity[7]:

haut-d(Y,X,D) $\equiv_{def} \exists$V (orient-haut(D,V) $\wedge$ V$\neq$X $\wedge$ loc(V) $\wedge$ ds-pôle(Y,X,D) $\wedge \forall$W (ds-pôle(W,X,D) => part(W,Y)))

We give below the definitions corresponding to the concept of pole (and inclusion in a pole). Basically we can say that the pole Y of an entity X in a direction D is constituted by the portion of X extending from the middle of X to its extremity in the direction D. These rules essentially rely on Allen's relations between the spatio-temporal referents of the previously mentioned elements (middle, extremity, etc.) in the direction D:

[7]It can be deduced (from the definition of vertical intrinsic orientation) that when the speaker is in a canonical position, the direction applied to the spatial configuration coincides with the gravitational upper direction.

$pôle(Y,X,D) \equiv_{def} \exists E,M$ $(part(Y,X) \wedge ext'(E,X,D) \wedge mil(M,X) \wedge m(stref(M),stref(Y),D) \wedge f(stref(E),stref(Y),D))$

$ds\text{-}pôle(Y,X,D) \equiv_{def} \exists U$ $(pôle(U,X,D) \wedge part(Y,U))$

On the basis of our orientational tools, we can introduce similar formal representations for the ILNs *bas* (bottom), *avant* (front), *arrière* (back). It is also possible to specify the semantic content of ILNs such as *dessus* (top extremity), *dessous* (bottom extremity), *devant* (front extremity), *derrière* (back extremity) using the same formalization of orientational phenomena. The only difference between the semantic definition of these lexemes and the representations associated to the ILNs *haut, bas, avant, arrière*, etc. concerns the topological and geometrical aspects. For instance, the *dessus* (top extremity) of an entity is the uppermost surface (roughly) perpendicular to the upper direction and in contact with the exterior of the entity. We obviously need here topological and geometrical concepts which are much more complex than the sole notion of pole in a direction. Various axioms are introduced in order to characterize an element which is an external surface perpendicular to a direction D and most advanced in this direction.

3.2.2.2 External localization

One of the goals of this study was to propose orientation tools which could be used to formalize the semantic content of internal as well as external localization lexemes.

Now, we are going to show how our formalism of orientation allows us to express the meaning of the external preposition *devant* (in front of). We can say that an entity Y is situated (intrinsically) in front of an entity X if Y is included in the space portion situated in front of X (that is to say the space portion delimited by means of X and its intrinsic frontal direction). In order to grasp such a configuration, we introduce the predicate ds-esp(Y,X,D) which specifies that an entity Y is included in the space delimited by the entity X and the direction D. From a more formal point of view this is expressed by stating that a relation m_i or > stands between the spatio-temporal referents of Y and X in the direction D:

$ds\text{-}esp(Y,X,D) \equiv_{def}$ $m_i >(stref(Y),stref(X),D)$[8]

Then we can characterize an entity Y situated intrinsically in front of an entity X setting down that Y has to be contained in the space delimited by X and the direction D which in turn constitutes the intrinsic frontal direction of X:

$être\text{-}devant\text{-}i(Y,X,D) \equiv_{def} orient\text{-}avant(D,X) \wedge ds\text{-}esp(Y,X,D)$

Here again the deictic use of the preposition *devant* (in front) differs from the intrinsic use in the underlying direction which is given by a speaker describing the configuration situated in front of him :

$être\text{-}devant\text{-}d(Y,X,D) \equiv_{def} \exists W$ $(orient\text{-}avant(-D,W) \wedge W \neq X \wedge W \neq Y \wedge loc(W) \wedge ds\text{-}esp(Y,X,D) \wedge être\text{-}devant\text{-}i(X,W,-D))$

The fact that the speaker is facing the landmark to which he gives a frontal orientation means that we consider a mirror configuration (between the orienting speaker and the landmark) and is expressed by the minus sign associated with the underlying direction of the predicate "orient-avant". In fact such deictic configurations are very frequent in French as opposed to the tandem ones which seem to be less often used.

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[8]This specification of "ds-esp" is sufficient because we only consider parallelepipedic, spherical or cylindrical entities. If we wanted to take into account more complex shapes (amphitheaters, arches and more generally curved objects) we would have to state a much more complicated formula. We tested it for some particular entities and we showed that some interesting inferential properties obtained on the basis of this simple version of "ds-esp" were lost.

3.2.3- Inferences

As we said previously in the description of our methodological choices, we wish to obtain a semantic representation of utterances allowing us to draw inferences which have to be in accordance with the deductions made by human beings. We already showed in (Aurnague & Vieu in press) that the inferences we can draw with the formal definitions *dans* (in), *sur* (on) as well as with ILNs such as *haut* (top), *devant* (front extremity), *dessous* (bottom extremity) match our commonsense intuitions. For instance from *le vase est sur le dessus de l'armoire* (the vase is on the top extremity of the cupboard) we can deduce that *le vase est sur le haut de l'armoire* (the vase is on the top of the cupboard). We will not give here the different steps of such a reasoning because it essentially relies on topological considerations and not on orientational ones (the reason is that the lexemes *haut* (top) and *dessus* (top extremity) have a similar semantic content from an orientational point of view and differ only in topological aspects).

However we are going to set out some of the inferences and calculations we are able to make using the semantic definitions previously proposed for the external preposition *devant* (in front of). We consider two sentences in which this preposition appears and we examine the results obtained by applying transitivity to their formal representations. We split the verification into three cases according to the deictic or intrinsic nature of the relation involved in each of the two sentences we combine.

3.2.3.1- Intrinsic-intrinsic case

An example of a utterance made up of two intrinsic *devant* (in front of) prepositions is[9]:

La table est devant le fauteuil

(The table is in front of the armchair)

Le fauteuil est devant l'armoire

(The armchair is in front of the cupboard)

Using the formal tools introduced for the preposition *devant*, we can give the following representation of these two sentences in which a, b and c respectively denote the armchair, the table and the cupboard:

être-devant-i(b,a,d1)

être-devant-i(a,c,d2)

If we know that the underlying directions of the two relations "être-devant" coincide (which is formally expressed by d1=d2) we can, on the basis of the axioms associated with the Allen's relations, deduce that ds-esp(b,c,d2) and finally that être-devant-i(b,c,d2). Consequently, we succeed in calculating that *la table est devant l'armoire* (the table is in front of the cupboard) intrinsically, given the two previous sentences and the additional constraint ensuring the coincidence between the intrinsic frontal direction of the armchair and the cupboard.

3.2.3.2- Deictic-deictic case

In a utterance such as the following, the landmarks involved in the two prepositions *devant* take their orientation from the speaker[10]:

La table est devant le lampadaire

(The table is in front of the light)

Le lampadaire est devant la plante

(The light is in front of the plant)

[9]Obviously these two sentences may be also interpreted in a deictic way. We make here the hypothesis that, when a lexeme pointing out a target with an intrinsic frontal orientation is identified in the text analyzed, the intrinsic interpretation of the preposition *devant* is chosen by default.

[10]In this case there is no more ambiguity because the two landmarks do not have any intrinsic frontal orientation so that only a deictic interpretation of the preposition *devant* is possible.

The speaker can linguistically express the fact that this description completely depends on its spatial position with respect to the configuration by adding at the beginning of each sentence, an expression such as *vu d'ici* (seen from here).

The following facts (based on the formal tools we described above) with a, b and c denoting respectively the light, the table and the plant express the semantic content of the previous sentences:

être-devant-d(b,a,d)

être-devant-d(a,c,d)

The same direction being associated with the two deictic relations "être-devant", we can here again calculate that ds-esp(b,c,d) and finally conclude that être-devant-d(b,c,d), which means that *la table est devant la plante* (the table is in front of the plant, deictically).

Obviously, if the underlying directions had been different, it would not have been possible to draw such an inference. This may occur when the spatial configuration is described from different positions or point of views in the two sentences (a same speaker occupying distinct positions at different moments or two speakers situated at distinct positions at the same moment).

3.2.3.3- Intrinsic-deictic case

The last case we consider here combines an intrinsic use of the relation "être-devant" with a deictic one:

La table est devant le fauteuil

(The table is in front of the armchair)

Le fauteuil est devant le lampadaire

(The armchair is in front of the light)

From the formal representation of these sentences (être-devant-i(b,a,d1) $\wedge$ être-devant-d(a,c,d2)), and with the same kind of calculation than previously applied, we succeed in deducing that *la table est devant le lampadaire* (the table is in front of the light, deictically: être-devant-d(b,c,d2)).

Once again, all the deductive process is conditioned by the coincidence between the intrinsic frontal direction of the armchair d1 and the deictic frontal direction d2 given to the light by a speaker w.

Before finishing the presentation of the functional level, it may be mentioned that the notions of distance and relative size between the trajector and the landmark play a great part in the semantics of most spatial prepositions. Actually, the importance of these notions increases when we consider combinations of the same relation (as in the utterances above) because they constitute factors that can block the application of transitivity. However, although distance and relative size rely on geometrical tools, their part is heavily affected by contextual factors. Consequently such phenomenons have to be described and formalized at the pragmatic level.

3.3- Pragmatic level

As we said in the beginning, we introduce at this level the underlying principles people use in order to filter out the relations inferred wrongly or in order to deduce more information than there actually is in the discourse.

The pragmatic level modifies the semantic obtained at the functional level according to context and world knowledge. We have not yet identified and formalized all the pragmatic factors arising in orientation phenomena but we are going to illustrate their part through the description of the axial priority principle.

As we showed at the functional level, the semantic representation of the preposition *devant* (in front of) constrains the positions of the trajector and the landmark with respect to the frontal axis. The definition stated that, from the moment the trajector Y is further on the frontal direction (associated to X) than the landmark X, Y can be described as being *devant* (in front of) X whatever its lateral position with respect to X is (Y can be on the left of/in front of/ on the right of X). Nevertheless, because of the enunciation context (spatial configuration surrounding X and Y, intentions of the speaker, etc.), we may want to say that *Y est exactement devant X* (Y is exactly in front of X) or *Y est davantage devant X que ne l'est* Z (Y is more in front of X than Z is), etc. The influence of the context can also be such that only the entities Y situated exactly in front of X will be described as being *devant* X.

By reducing the degree of freedom on the lateral axis this pragmatic phenomenon amounts to make a focus on the frontal direction; we call this "axial priority". In order to formalize the axial priority phenomenon we introduce several definitions constraining the position of two entities Y and X (representing the trajector and the landmark) with respect to a horizontal direction D' which is orthogonal to the focused direction D. In fact we consider four cases of axial priority. The first one takes into account the cases o and oi (overlapping of the extension intervals) whereas the fourth corresponds to = (equality configurations). From their part, the second and the third definitions of axial priority group together respectively the relations si di fi (inclusion of X in Y along D) and the converse ones s, d, f (inclusion of Y in X along D)[11]:

prio-axiale-horiz1(Y,X,D) $\equiv_{def}$ $\exists$D' (ortho(D,D') $\wedge$ ortho(D',haut-grav) $\wedge$ ooi(stref(Y),stref(X),D'))

prio-axiale-horiz2(Y,X,D) $\equiv_{def}$ $\exists$D' (ortho(D,D') $\wedge$ ortho(D',haut-grav) $\wedge$ sifidi(stref(Y),stref(X),D'))

prio-axiale-horiz3(Y,X,D) $\equiv_{def}$ $\exists$D' (ortho(D,D') $\wedge$ ortho(D',haut-grav) $\wedge$ sfd(stref(Y),stref(X),D'))

prio-axiale-horiz4(Y,X,D) $\equiv_{def}$ $\exists$D' (ortho(D,D') $\wedge$ ortho(D',haut-grav) $\wedge$ =(stref(Y),stref(X),D'))

Classifying in such a way the possible configurations of the entities on the lateral axis we introduce a way of making differences among the different entities situated *devant* (in front of) a given entity X.

However, a complete formalization of this phenomenon of axial priority would require a precise study of the contextual elements leading to these restrictions.

4- Conclusion

Grounding our research on a detailed semantic analysis we have proposed a formalization of orientation which allows us to represent the semantic content of spatial expressions such as *le haut* (the top), *l'arrière* (the back), *être devant* (to be in front), *être au dessous* (to be above), etc. We have showed that these formal definitions could be used in order to draw inferences matching the conclusions of natural (i.e. human) reasoning.

This modular representation of orientation (and more generally of space in language) constitutes, from this point of view, a real cognitive approach.

If we go back to the goals we set for this study in the beginning, it can be underlined that both have been fulfilled because our formal tool correctly grasps the differences between intrinsic and deictic orientation and can be used furthermore to deal with internal localization as well as external localization. Our guess is that these properties of the formalism correctly account for

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[11]The numbering of these definitions does not obligatory imply a greater acceptance for the considered spatial relation. For instance, although two entities verifying the axial priority 2, 3 or 4 will be more "in front of" than if they were in the configuration 1, it is not always clear which of the configurations 2, 3 or 4 is the best.

some of the mechanisms underlying the cognitive processing of orientation.

Besides the points previously mentioned (notion of relative distance between trajector and landmark, pragmatic phenomena, etc.), we contemplate increasing this work on two main points. From a logical point of view, we would want to be able to compare directions relatively (in order to express notions such as "Direction D1 is closer to D3 than D2 is) and to introduce composition operations between them (Freksa 92). It would be also desirable to adapt the formalism to integrate both spatial and temporal data and process utterances describing moving or changing configurations.

Concerning the cognitive aspects, we plan to elaborate, with various psycholinguists and psychologists, experimentations in order to test some of the hypotheses related to our formal tools or in order to bring to the fore important properties or concepts of orientation in language (Borillo M. 91).

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A Semantic Approach to the Translation of Locative Prepositions

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0. Abstract

Prepositions are known to be the source of a wide range of translation mismatches. Therefore their treatment is a notoriously difficult task for machine translation (MT). In this paper I show how one can handle the German-Russian translation of spatial prepositions. I propose semantic representations for locative prepositions which express a spatial relation between two concrete objects. The representation language is based on tools from set-theoretic topology. Objects are represented as sets of spatial points and the relations between them are expressed in terms of inclusion, overlap and connection.

The proposed semantic representations for the German and Russian locative prepositions can be used to infer whether the meaning of the target language (TL) preposition is identical, more general or more specific to that of the source language (SL). These correspondences between SL and TL representations are established by use of identity, superset and subset relations between the sets of spatial points expressed in the prepositions' meaning representations.

First, I introduce the translation picture we are faced with. Second, I present the formal representation language and focus more specifically on issues that concern the meaning representation for spatial expressions in the lexicon. Then, I show how the correspondence between SL and TL representations is established. Finally, I propose a translation model which involves an inference-driven mapping between meaning representations.

1. Introduction

In this paper I take into consideration spatial relations between two concrete objects expressed by the German locative prepositions "in"('in'), "auf"('on'), "an"('on, next to') and their Russian equivalents "v"('in'), "na"('on') and "u"('next to') respectively. These are expressions of the type "der Käse <u>auf</u> dem Tisch" ('the cheese <u>on</u> the table'), where the PP is a modifier which attributes the property of being located "on the table" to the individual "cheese".

Furthermore the localized object (LO) "cheese" is situated with respect to a particular spatial portion of its reference object (RO) "table", namely its top surface, referred to by the preposition "auf"('on').

In recent years a wide range of approaches to spatial relations has appeared, for example, the prototype semantics' approach taken by [HERSKOVITS 1986, LAKOFF 1987] or the two level approach proposed by [BIERWISCH 1988, LANG 1987, HERWEG 1988]. But among the great variety one can find only a few approaches which aim at a formal semantic representation for spatial prepositions, e.g., those taken by [LUTZEIER 1974, MOILANEN 1979] and [AURNAGUE/VIEU 1992]. In contrast to a prototype semantics' approach, which puts forward the idea of an "idealized meaning ", or a two level approach, which assumes a primitive meaning on a semantic level which is more finely articulated on a second conceptual level, I regard the meaning of the spatial preposition as the disjunction of all its possible interpretations. The relation of the type "LO LOCATIVE PREPOSITION RO" is understood as a relation between spatial entities where the spatial referent of the RO is determined by the preposition and the LO is mapped onto that portion of space which actually participates in the spatial relation.

The application to the domain of machine translation restricts the depth of the semantic representations to a certain amount. They have to capture at least all the distinctions made in the languages involved. I will basically make use of topological representations to capture the meaning of the spatial prepositions. For the prepositions considered functional relations are ignored since they are obvious from the spatial configuration between the involved objects.

2. The translation picture

In order to motivate the semantic representations for locative prepositions given in section four, I will introduce the translation picture we are faced with. Concerning the language pair German-Russian, the following types of translation patterns can be distinguished:

I. Equivalence

If two prepositions in different languages share the same meaning they are assumed to be equivalent. The preposition "in"('in'), for example, captures the same set of interpretations as the Russian preposition "v"('in'), i. e., the partial and complete inclusion in an empty as well as in a materially occupied interior. This is shown in the examples (1-4) and (1'-4') respectively:

(1) die Milch <u>in</u> der Flasche	(1') moloko <u>v</u> butylke	('the milk in the bottle')
(2) der Löffel <u>in</u> der Tasse	(2') ložka <u>v</u> čaške	('the spoon in the cup')
(3) der Fisch <u>im</u> See	(3') ryba <u>v</u> ozere	('the fish in the lake')
(4) der Nagel <u>in</u> der Wand	(4') gvozd' <u>v</u> stene	('the nail in the wall')

II. Translation mismatches involve cases where one language encodes a spatial relation not directly expressible in the other. Here three different kinds can be distinguished:

A. Generalization

The TL preposition has a *more general meaning* than the SL preposition. E.g., the meaning of the German preposition "auf"('on'), which refers primarily to the top surface of its reference object, as in (5, 6), and which can be used to refer to a vertical surface only in a very restricted way, as in (7), is covered by the Russian preposition "na"('on'). But "na" has a wider domain of application. It highlights the contact with any surface of its reference object. This is shown in the examples (5'-10').

(5) das Buch auf dem Tisch	(5') kniga na stole	('the book on the table')
(6) der Schornstein auf dem Dach	(6') truba na kryše	('the chimney on the roof')
(7) der Schweiß auf/an der Stirn	(7') pot na lbu	('sweat on the forehead')

B. Specification

The differentiation between spatial relations captured in the TL is not expressible in the SL, i.e., the meaning of the SL preposition is expressed by more than one TL preposition. We are faced with a *specification in the TL* which forces a choice not made in the SL. If we translate the Russian preposition "na"('on'), which primarily refers to any surface of its RO, we have to choose between "an" and "auf" in German. They both render this meaning, as can be seen in (8-10). A similar problem arises if we translate "an"('on', 'next to') into Russian. Here "na"('on') is used if there is contact with the RO's surface and "u"('next to') if the LO is situated in the region which surrounds the RO. This is shown in (9',10') in contrast to (11').

(8') kniga na stole	(8) das Buch auf dem Tisch	('the book on the table')
(9') kartina na stene	(9) das Bild an der Wand	('the painting on the wall')
(10') vyključatel' na lampe	(10) der Schalter an der Lampe	('the switch on the lamp')
(11') derevo u doma	(11) der Baum am Haus	('the tree next to the house')

C. Idiosyncracies

A language specific idiosycratic use of a preposition is another reason for a translation mismatch. This problem is widely discussed and most often handled in the cognitive framework of prototype semantics. Cognitive semanticists explain the idiosycratic use of a preposition by a distinct language specific conceptualization of spatial entities. These ideas are also reflected in MT approaches to locative prepositions [JAPKOWICZ/WIEBE 1991] and [ZELINSKY-WIBBELT 1990]. They represent the preposition's meaning as an idealized spatial relation between spatial entities schematized as volumes, surfaces or points. I treat spatial entities according to the way they appear in our world and not as they may be conceptualized occurring in connection with a certain preposition. Moreover, it does not always seem to be appropriate to think of a surface when the Russian native speaker uses the preposition "na" ('on') for reference to an interior, e.g.:

(12) Weizen in der Mühle (12') pšenica na mel'nice ('wheat *on* the mill')

(13) die Maschinen in der Fabrik (13') stanki na fabrike ('mashis *on* the factory')

This use of the preposition "na" ('on'), which is rather productive in Russian, can be explained only historically, e.g., by reference to an undifferentiated interior like that of a factory as to the whole factory territory or by the influence of the institutional reading which is also expressed by the preposition "na". Nowadays the meaning of such an expression is obviously inclusion in an interior without any necessary contact with a surface. On the other hand, it is more reasonable to think of a different conceptualization when the object has an intermediate shape which accounts for the usage of "na", e.g.:

(14) das Ei in der Pfanne (14') jajco na skovorotke ('the egg *on* the pan')

(15) der Sportler im Stadion (15') sportsmen na stadione ('spotsmen *on* the stadium').

But even if one might be able to explain the use of the Russian "na" discussed above, there is no way to predict for which objects it holds. Therefore, the affected objects have to be marked in the lexicon.

3. Formal tools - the definition of spatial regions

In order to understand the prepositions' meaning representations I will briefly introduce some formal specifications of the representation language used here. Spatial properties of objects, and the relations between them, are expressed in terms of set-theoretic topology. In other approaches, like [AURNAGUE/VIEU 1992], the representation of spatial prepositions is based on connection theorie [CLARKE 1981], where spatial entities are regarded as individuals. Here, following [LUTZEIER 1974, MOILANEN 1979], spatial entities are defined as sets of spatial points. Then, spatial prepositions denote relations between particular subsets of these point sets. These relations are expressed in terms of inclusion, overlap and connection.

Localization is regarded as a time-dependent function mapping individuals to their spatial referents, i.e. to sets of spatial points. Using the definitions of interior, exterior and boundary points from topology the space an object "a" occupies at time "t" equals the set of its interior points INT(<a,t>). I distinguish between materially occupied and empty interior points. The surrounding region of an object is defined as the set of its exterior points EXT(<a,t>).

A space-assignment function p maps the object "a" to the space it occupies. This is the union of its materially occupied INT-MAT(<a,t>) and non-materially occupied interior points INT-EMPTY(<a,t>). The space which is taken up by an object is assumed to be connected.

The space-assignment function p[1]

Assume I to be a set of individuals, T a set of time intervals, P a set of places

$p\colon I \times T \rightarrow P$

for all $a, b \in I$, $t \in T$: if $p(<a,t>) \neq \emptyset$ and $p(<b,t>) \neq \emptyset$ and

$p(<a,t>) = p(<b,t>)$, then $a = b$.

$\text{INT-MAT}\colon I \times T \rightarrow P$ and $\text{INT-EMPTY}\colon I \times T \rightarrow P$ such that for all $a, b \in I$, $t \in T$:

$p(<a,t>) = \text{INT-MAT}(<a,t>) \cup \text{INT-EMPTY}(<a,t>)$ and

$\text{INT-MAT}(<a,t>) \cap \text{INT-EMPTY}(<a,t>) = \emptyset$ and $p(<a,t>)$ is connected.

Hence, the empty interior of a vase, for example, as well as its material hull belong to the space the vase occupies. Making the distinction between materially occupied and empty spatial points, the surface of an object can be defined in the following way:

$\text{SURF}(<a,t>) = \{\, p \mid N(p) \cap \text{INT-MAT}(<a,t>) \neq \emptyset \wedge N(p) \cap e(<a,t>) \neq \emptyset \,\}$

The surface of an object "a" consists of all points p whose neighborhood N(p) is partially contained in the set of materially occupied spatial points, INT-MAT(<a,t>), and partially in its exterior e(<a,t>). To expess the meaning of the prepositions in question, further subsets of the object's surface and its exterior have to be defined. Assuming a metric topological space with an underlying coordinate system and making use of the distance function these subsets can be defined. Figure 1 exemplifies some of them for a vase:

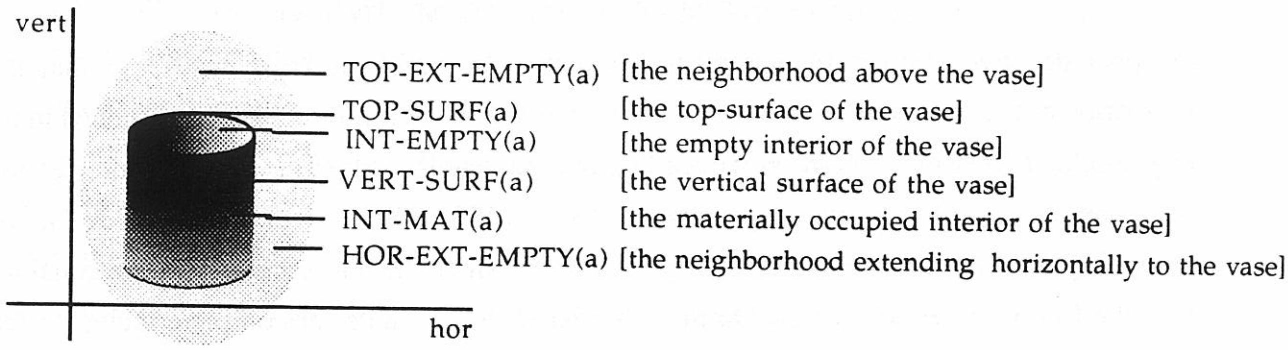

fig. 1

First, the empty exterior above the object, TOP-EXT-EMPTY(<a,t>), is defined using the distance measure between two points along the vertical in the direction against gravity $d_{+vert}(x, y)$.

$\forall x \forall y \;\; x \in p(<a,t>)$ and $y \in \text{EXT-EMPTY}(<a,t>)$

$\text{TOP-EXT-EMPTY}(<a,t>) = \{y \mid d_{+vert}(x, y) > 0\}$

Applying then the definition of the boundary, the top surface is defined in the following way:

$\text{TOP-SURF}(<a,t>) = \{p \mid N(p) \cap \text{INT-MAT}(<a,t>) \neq \emptyset \wedge N(p) \cap \text{TOP-EXT-EMPTY}(<a,t>) \neq \emptyset\}$

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1 In a similar way an exterior-assignment function e(<a,t>) is defined.

The bottom surface is defined analogously and the vertical side surface is derived by the set-theoretical difference between the whole surface and the top and bottom surface.

Between these different spatial regions the following relations obtain:

(16) $\text{TOP-SURF}(\langle a,t\rangle) \subset \text{SURF}(\langle a,t\rangle)$

(17) $\text{VERT-SURF}(\langle a,t\rangle) \subset \text{SURF}(\langle a,t\rangle)$

(18) $\text{INT-MAT}(a) \cap \text{INT-EMPTY}(a) = \varnothing$

(19) $\text{EXT}(\langle a,t\rangle) \cap \text{INT}(\langle a,t\rangle) = \varnothing$

These statements are part of the knowledge which is used to mediate between non-identical SL and TL representations (see section five).

4. The meaning representations of locative prepositions in the lexicon

Now I will use the formal language to describe the meaning of locative prepositions. The meaning of a spatial preposition is represented fully independently of any TL-requirements. It is the disjunction of all its possible interpretations. The relation of the type "a PREPOSITION b" where "a" is the LO and "b" the RO is valid if and only one of the possible representations is true.

The German preposition "in"('in') is represented in (20):

(20) a IN b $\Leftrightarrow$ (a) $p(\langle a,t\rangle) \cap \text{INT-EMPTY}(\langle b,t\rangle) \subset \text{INT-EMPTY}(\langle b,t\rangle) \vee$

(b) $p(\langle a,t\rangle) \cap \text{INT-MAT}(\langle b,t\rangle) \subset \text{INT-MAT}(\langle b,t\rangle)$

"In" provides two distinct interpretations. On the one hand the (a) clause says that the intersection of the space occupied by the LO and the empty interior of the RO is contained in the latter. Such a representation covers the reading of complete inclusion, in which the intersection equals the place the LO occupies: $p(\langle a,t\rangle) \cap \text{INT-EMPTY}(\langle b,t\rangle) = p(\langle a,t\rangle)$ (cf. ex.1), and the reading of partial inclusion in an empty interior, in which the intersection does not equal the place the LO occupies (cf. ex.2). On the other hand (b) accounts for complete inclusion (cf. ex.3) as well as for partial inclusion in a materially occupied interior (cf. ex.4). On this representation level no distinction between complete and partial inclusion is made, since German and Russian do not lexicalize this distinction.

The preposition "auf"('on') has a more complex interpretation, as can be seen in (21):

(21) a AUF b $\Leftrightarrow$ (a) $\text{PART}(\text{SURF}(\langle a,t\rangle)) \copyright \text{TOP-SURF}(\langle b,t\rangle)$

(b) $\text{INT-MAT}(\langle a,t\rangle) \cap \text{INT-MAT}(\langle b,t\rangle) \subset \text{TOP-SURF}(\langle b,t\rangle) \vee$

(c) for specially marked objects: $\text{SURF}(\langle a,t\rangle) \copyright \text{VERT-SURF}(\langle b,t\rangle) \vee$

(d) if the German RO is marked for that idioysncratic use:

$p(\langle a,t\rangle) \cap \text{INT-EMPTY}(\langle b,t\rangle) \subset \text{INT-EMPTY}(\langle b,t\rangle)$

According to (a) the preposition "auf" expresses that subsets of the surface of the LO (PART(SURF(<a,t>)) are in contact with the top surface of the RO[2] (cf. ex.5). This is the default reading of "auf". It presupposes the existence of a vertical direction and of gravity. Hence, the functional relation of support could easily be derived from the given spatial configuration. The (b)-clause says that the intersection of the material interior of the objects involved is contained in the top surface of the RO. This abstraction should capture the "embedding" of the LO in the top surface of the RO (cf. ex.6). The homogeneous contact of the whole surface of the LO with the vertical surface of the RO expressed in (c) is a rather restricted use. Therefore the possible reference objects have to be marked in the lexicon (cf. ex.7). Finally, (d) shows that "auf" can also be used to highlight the empty interior of its reference object. Again this use is restricted to a couple of objects and cannot be predicted (cf. die Lampe auf dem Flur ('the lamp *on* the floor')).

Now let's look at the spatial meaning of the preposition "an"('on', 'next to') in (22):

(22) a AN b $\Leftrightarrow$ (a) $PART(SURF(<a,t>)) \copyright VERT\text{-}SURF(<b,t>) \vee$

(b) $INT\text{-}MAT(<a,t>) \cap INT\text{-}MAT(<b,t>) \subset SURF(<b,t>) \vee$

(c) for strictly bounded objects: $p(<a,t>) \subset HOR\text{-}EXT\text{-}EMPTY(<b,t>)$

In (a) "an" captures the contact of a surface of the LO with a vertical surface of the RO (cf. ex.7,9). Representation (b) denotes that the LO is an appendage of the RO which is embedded in its surface (cf. ex.10). This representation overlaps with (21b). Here (22b) is assumed to be the default interpretation, if we can exclude the embedding in a top-surface denoted by (21b). The more specific representation is given preference. Under (c) "an" says that the LO is situated in the RO's exterior, which extends horizontally to it. It is valid only if the RO is a strictly bounded object (cf. ex.11). Now I turn to some Russian locative prepositions.

First, the meaning of "v"('in) is represented in (23). It captures exactly the same set of interpretation as the German preposition "in" does, (cf.ex. 1'-4').

(23) a V b $\Leftrightarrow$ (a) $p(<a,t>) \cap INT\text{-}EMPTY(<b,t>) \subset INT\text{-}EMPTY(<b,t>) \vee$

(b) $p(<a,t>) \cap INT\text{-}MAT(<b,t>) \subset INT\text{-}MAT(<b,t>)$

As we can see in (24) the Russian locative preposition "na" ('on') has a wider reading:

(24) a NA b $\Leftrightarrow$ (a) $PART(SURF(<a,t>)) \copyright SURF(<b,t>) \vee$

(b) $INT\text{-}MAT(<a,t>) \cap INT\text{-}MAT(<b,t>) \subset SURF(<b,t>) \vee$

(c) if the Russian RO is marked for that idioysncratic use:

$p(<a,t>) \cap INT\text{-}EMPTY(<b,t>) \subset INT\text{-}EMPTY(<b,t>)$

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2 The sign © stands for the connectedness between the two point sets, which expresses the contact relation between the surfaces of the objects involved.

As shown in (a) "na" expresses the contact of the LO's surface with any surface of its RO (cf. ex.5', 7', 8', 9'). The (b)-clause says that a part of the LO is embedded in the RO's surface (cf. ex.6',10'). The third meaning (c) captured by "na" is its reference to an empty interior, which is valid only for lexically marked objects (cf. ex.12'-15').

Finally, the representation (25) indicates that the Russian preposition "u" ('next to') is used to situate an object in the surrounding region of the RO which extends horizontally to it (cf. ex.11').

(25) $a\ U\ b \Leftrightarrow p(\langle a,t\rangle) \subset \text{HOR-EXT-EMPTY}(\langle b,t\rangle)$

5. The correspondence between source and target language representations

Now we apply the introduced meaning representations for spatial prepositions to the domain of MT. In an interlingual MT system the meaning representation is assumed to be shared by all languages involved. But it turned out that that "there is no hope of constructing a language IL [interlingua] which is such that translations in all languages map onto a single abstract representation in IL" ([KAY 1991], p. 78). Even if the ambitions of the IL-approach are confined to the design of a meaning representation mediating between two languages there are many translation mappings which cannot share the same representation. Because of translation mismatches intra-lingual mappings between IL representations are often inevitable. Now the question arises how these mappings can be achieved in an efficient way preserving language-pair independence in the lexicon.

If we look at the translation picture in section one, it turns out that the analysis can be guided by TL requirements. In the case where the SL representation is completely shared by a TL preposition (I.identity) the mapping is trivial. If the meaning of the SL preposition is a submeaning of a TL preposition (II.A generalization) then the more general TL representation is the appropriate one. If the TL makes a distinction not made in the SL (II.B specification), an analysis is indispensible, and must go as deep as the TL specification. If the use of the TL preposition is idiosnycratic (II.C idiosyncrasy) then the mapping is justified if the lexical markedness of the corresponding RO indicates that.

How can these ideas be realized in a MT model? First, the preposition is replaced by the disjunction of all its possible meanings and sent to the negotiator. The latter finds in the TL lexicon all meaning representations from which a corresponding TL preposition can be derived. Comparing each disjunct of the given SL representation with the TL representations in the TL lexicon, we have to find those from which the appropriate TL preposition can be derived. These are TL representations which are identical to one of the given SL representations or which share partially at least one of those. Here knowledge about the sets of spatial points described in the prepositions' meaning representations is used to infer (i) which are the corresponding TL representations and (ii) which relation holds between the SL and TL representations. This relation points out the kind of translation mismatch. Consequently, it suggests the appropriate mapping level. More precisely, if the set of spatial points of the RO expressed in the TL representation is a *superset* of the one expressed in the SL representation, thereby assuming identity between the remaining parts of the SL and TL propositions, then we are faced with a *generalization in the TL*. Here the translation mapping is allowed since the SL-representation logically implies the TL representation. If the set of spatial points the RO in the TL refers to is a *subset* of the set the RO in the SL refers to, then a *specification in the TL* is recognized. If there is more than one such TL representation from which different prepositions can be derived, no mapping can be carried out. An analysis according to the TL specification is then indispensable.

Hence, the correspondences between SL and TL representations are inferred on the basis of identity, superset and subset relations between the sets of spatial points described in the prepositions' meaning representations. Let me make this more concrete with some examples. We want to translate the German preposition "auf" into Russian. It is replaced by the expressions (21a-d):

(21a) $\text{PART(SURF(<a,t>))} \copyright \text{TOP-SURF(<b,t>)} \vee$

(21b) $\text{INT-MAT(<a,t>)} \cap \text{INT-MAT(<b,t>)} \subset \text{TOP-SURF(<b,t>)} \vee$

(21c) for specially marked objects: $\text{SURF(<a,t>)} \copyright \text{VERT-SURF(<b,t>)} \vee$

(21d) if the German RO is marked for that idiosyncratic use:
$\text{p(<a,t>)} \cap \text{INT-EMPTY(<b,t>)} \subset \text{INT-EMPTY(<b,t>)}$

Here the following TL-representations are picked out:

(24a) $\text{PART(SURF(<a,t>))} \copyright \text{SURF(<b,t>)} \vee$

(24b) $\text{INT-MAT(<a,t>)} \cap \text{INT-MAT(<b,t>)} \subset \text{SURF(<b,t>)} \vee$

(24c) if the Russian RO is marked for that idiosyncratic use:
$\text{p(<a,t>)} \cap \text{INT-EMPTY(<b,t>)} \subset \text{INT-EMPTY(<b,t>)} \vee$

(23a) $\text{p(<a,t>)} \cap \text{INT-EMPTY(b)} \subset \text{INT-EMPTY(<b,t>)}$

These representations are found in the following way: given (16) $\text{TOP-SURF(<a,t>)} \subset \text{SURF(<a,t>)}$, it can be inferred that (21a) is a submeaning of (24a) and (21b) is a submeaning of (24b). If it turns out that the German objects are marked for meaning (21c) then according to (17) $\text{VERT-SURF(<a,t>)} \subset \text{SURF(<a,t>)}$, (21c) is a submeaning of (24a). Moreover, if the German RO is used with the preposition "auf" to refer to an empty interior (21d), then (24c) and (23a) are the corresponding representations because of the identity relation.

If the German RO is used idiosyncratically then representation (21d) is the appropriate one . Here the lexical information on the Russian RO is decisive for the choice between "v"('in') or "na"('on') in the TL. If one of the remaining representations (21a-c) is valid the mapping is also straightforward, because the set to which the target language RO refers is a superset of that to which the RO in the SL refers. This relation entails a generalization in the TL, i.e., an analysis is not necessary. Consequently, the mapping to the more general representations (24a, b) is allowed and the Russian preposition "na" is generated.

Now let us consider a more complicated case, the translation of the Russian preposition "na"('on'), which has the following meaning:

(24a) $\mathrm{PART}(\mathrm{SURF}(\langle a,t\rangle)) \copyright \mathrm{SURF}(\langle b,t\rangle) \vee$

(24b) $\mathrm{INT\text{-}MAT}(\langle a,t\rangle) \cap \mathrm{INT\text{-}MAT}(\langle b,t\rangle) \subset \mathrm{SURF}(\langle b,t\rangle) \vee$

(24c) if the Russian RO is marked for that idiosyncratic use:

$p(\langle a,t\rangle) \cap \mathrm{INT\text{-}EMPTY}(\langle b,t\rangle) \subset \mathrm{INT\text{-}EMPTY}(\langle b,t\rangle)$

In this case a lot of corresponding representations are found:

(21a) $\mathrm{PART}(\mathrm{SURF}(\langle a,t\rangle)) \copyright \mathrm{TOP\text{-}SURF}(\langle b,t\rangle) \vee$

(21b) $\mathrm{INT\text{-}MAT}(\langle a,t\rangle) \cap \mathrm{INT\text{-}MAT}(\langle b,t\rangle) \subset \mathrm{TOP\text{-}SURF}(\langle b,t\rangle) \vee$

(21c) for specially marked objects: $\mathrm{SURF}(\langle a,t\rangle) \copyright \mathrm{VERT\text{-}SURF}(\langle b,t\rangle) \vee$

(21d) if the German RO is marked for that idiosyncratic use:

$p(\langle a,t\rangle) \cap \mathrm{INT\text{-}EMPTY}(\langle b,t\rangle) \subset \mathrm{INT\text{-}EMPTY}(\langle b,t\rangle) \vee$

(22a) $\mathrm{PART}(\mathrm{SURF}(a)) \copyright \mathrm{VERT\text{-}SURF}(\langle b,t\rangle) \vee$

(22b) $\mathrm{INT\text{-}MAT}(\langle a,t\rangle) \cap \mathrm{INT\text{-}MAT}(\langle b,t\rangle) \subset \mathrm{SURF}(\langle b,t\rangle) \vee$

(20a) $p(\langle a,t\rangle) \cap \mathrm{INT\text{-}EMPTY}(\langle b,t\rangle) \subset \mathrm{INT\text{-}EMPTY}(\langle b,t\rangle)$

These TL representations are picked out in the following way: on the one hand (24a) includes (21a) and (24b) includes (21b) since (16) $\mathrm{SURF}(\langle a,t\rangle) \supset \mathrm{TOP\text{-}SURF}(\langle a,t\rangle)$. On the other hand, given (17) $\mathrm{SURF}(\langle a,t\rangle) \supset \mathrm{VERT\text{-}SURF}(\langle a,t\rangle)$, it can be inferred that (21c) and (22a) are contained in (24a). (24b) and (22b) are identical. In the case of appropriate lexical information on the Russian RO, (24c) is identical with (20a) and with (21d) if the German RO is also used idiosyncratically.

Here the mapping is allowed only if the Russian RO makes an idiosyncratic use of the preposition "na". In this case no other SL interpretation is valid since the idiosyncratic use is always given preference. Because of the identity relation the mapping can be processed. Comparing the remaining SL and TL representations a specification in the TL can be inferred because the sets to which the target language ROs refer are subsets of that to which the ROs in the SL refers. From the TL interpretations found two different prepositions, namely "auf" and "an", can be generated, i.e., the translation mapping cannot be processed. The analysis has to show which of the TL representations is the appropriate one in the given situation. This is done using knowledge about the topological properties of the RO and the functional relations between the two objects involved.

6. The translation model

How can these ideas be realized in a MT model? Following basically the ideas of the "Translation-by-Negotiation-Approach" proposed by [KAY 1991], a translation model which makes use of the introduced meaning representations and the inference-guided mapping between them may look like the following in figure 2.

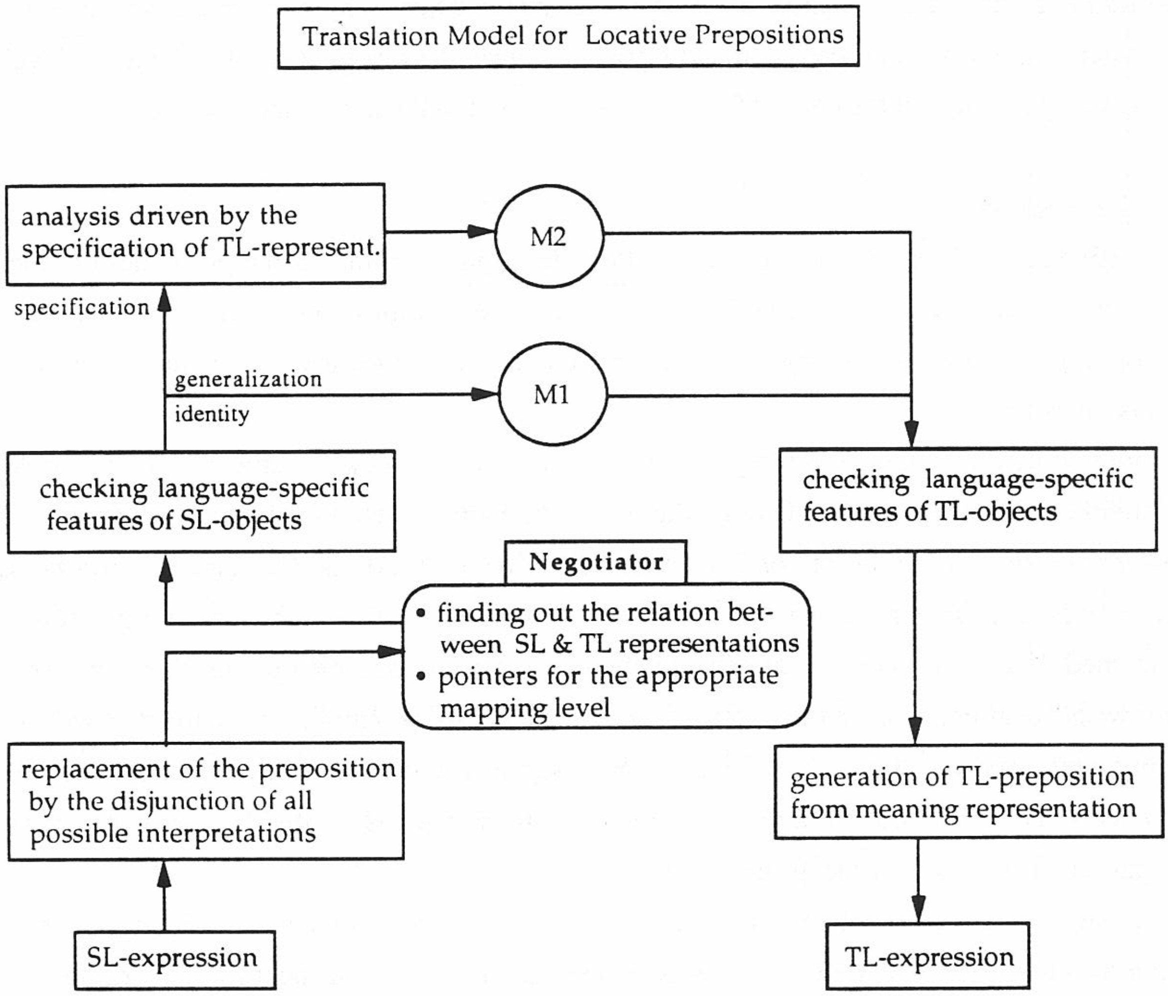

fig. 2

Ignoring here the syntactic analysis, first the preposition is replaced by the disjunction of all its possible meanings. On this level no analysis is carried out to find the appropriate one among the possible SL interpretations. The whole bundle of possible meanings is sent to the negotiator.

The latter finds all representations in the TL lexicon from which a corresponding preposition can be derived. If only identical representations are found or if all corresponding TL representations have a more general meaning, then the mapping is straightforward (M1). In the case of an idiosnycratic use of the SL or TL preposition the mapping is determined by the lexical marking of the corresponding RO. If the negotiator finds only more specific TL representations, from which different prepositions are generated, the analysis must go as deep as the TL specification requires. If one of them is found the mapping (M2) is carried out. Then, the TL preposition is generated from the appropriate TL representation.

This way an efficient translation mapping can be carried out. Using an appropriate uniform formal representation for the languages involved we can get by with a monolingual description maintaining the language-independence assumption.The recognized kind of translation mismatch suggests the appropriate mapping level. Hence, the mapping is carried out at a level as shallow as possible and the depth of analysis is restricted to the necessary amount.

7. The lexicon

The defined spatial regions (see section 3) allow descriptions of the spatial properties of objects and consequently a classification of spatial objects. The ontology found here reflects above all the topological properties of objects, which are relevant for the locative prepositions considered in this investigation.

Without going into detail I want to give some of the classificational criteria used in the ontology of three-dimensional objects. One of them is a distinction based on the composition of the object's interior. If it consists only of materially occupied points then either a non-hollow massive object, as e.g., a brick or a lake, or a substance, as e.g., water or wood, is concerned. If an object consists of exclusively non-materially occupied points, then it refers to a hollow space, as e.g., a cave or a ditch. If an object consists of materially occupied as well as of empty interior points, then it is either a hollow body, as for example, a cup or a bus, or a group of objects, as e.g., a forest or a town, where the hollow space is created by the space between the particular members of the group.

Moreover, it is decisive whether the interior is closed or open. Other classificational criteria concern the surface of the object, its boundedness, its canonical position according to the earth's surface and its typical neighborhood.

The ontology allows the description of the topological properties of spatial entities as properties of a whole class. This makes possible an efficient spatial description of objects in the lexicon. A lexicon, applicable to a MT model, is shown in figure 3.

Under the condition that a noun in both languages denotes the same object in the world, an identical spatial referent can be assumed. In this case the spatial features can be shared by SL and TL objects in a common part of the lexicon. Language-specific information, such as the meaning of the locative prepositions and the idiosyncratic use of prepositions are kept separately.

Lexicon

SL-Lexicon		TL-Lexicon
• meaning of locative SL-prepositions		• meaning of locative TL-prepositions
•SL-objects .... marking of idiosyncratic use and other language- specific restrictions	objective spatial features p(<a,t>) = ... e(<a,t>) = ... SURF(<a,t>) = ... Boundedness = ...	•TL-objects .... marking of idiosyncratic use and other language- specific restrictions

fig. 3

8. Conclusion

In this paper semantic representations for locative prepositions have been proposed. It was shown that these representations can be used as an interlingua in a MT model. The formal representation language makes it possible to find out the actual relation between SL and TL representations and to determine the appropriate mapping level. Under the condition of identity between SL and TL representations or a generalization in the TL the translation mapping is straightforward. In the case of a specification in the TL an analysis according to TL requirements is necessary. Further investigations should concentrate on the problem of what knowledge has to be involved in deciding which is the appropriate TL representation.

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Spatio-temporal semantics in Natural Language : the case of motion

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Abstract

Developing suitable representations for formalizing time and space knowledge has always been of a great importance in Artificial Intelligence (AI) and cognitive science. We here present a new way to conjoin these two problems. From the linguistic study of motion (which is the best concept to associate space and time at the lexical and phrase levels), realized by Laur (1991), we construct a system to represent the spatio-temporal semantics of motion. This linguistic analysis consists in a semantic classification of the French motion verbs and spatial prepositions and in the elaboration of compositional rules between the semantic classes of these verbs and these prepositions. Our system, based on a two-level semantics representation, allows to formally represent the results drawn by the linguistic part and to perform some kinds of natural spatio-temporal reasoning.

1. INTRODUCTION

Formalizing time and space knowledge is an important topic in AI and cognitive science. The work we present here takes place in the framework of the study of formal semantics of natural language. Recent studies (cf. Vieu 1991, Aurnague 1991) have shown that space, as it is described in natural language, is strongly linked to time. We are interested in the way of formalizing spatial cognitive concepts as they are revealed by natural language, ie. by also considering their temporal dimension. The concept of motion is interesting because it allows for the description of spatial places following each other in time. Two major components are used in expressions of motion : motion verbs and spatial prepositions.

We present the linguistic study of Laur on motion verbs (§2.2), spatial prepositions (§2.3) and their semantic combinations (§2.4). Its results lead to the elaboration of a two-level semantics (§3.1). This linguistic study has shown the correlation between the links among typical places and the semantics of expressions of motion. We introduce some markers to catch these typical places at the representational level (§3.2). Expressing the links between typical places then amounts to represent links between our markers using formal relations. We present and discuss currently used formalisms and look in detail which properties an adequate one needs to have (§3.3). The closer one to our concern is the Mereology of Clarke (§3.4). It is unfortunately not completely adequate and some extensions are required (§3.5). We propose a representation of spatial entities and temporal events as spatio-temporal individuals, defined by both spatial and temporal constraints. This assures spatio-temporal continuity, which is crucial in performing spatio-temporal reasoning (§3.7). We introduce representational rules for both levels of semantics (§3.6). We finally provide an example showing how these formal representations can be easily and shortly manipulated, and, therefore, how they are interesting for performing natural spatio-temporal reasoning (§3.7).

2. A LINGUISTIC APPROACH

2.1. *Introduction*

The linguistic study of Laur (1991) establishes the precise role of motion verbs and spatial prepositions in expressions of motion in French. The methodology consists to bring out their intrinsic spatial and temporal characteristics out of any context and independently of their combination. Only in a second time, the semantics of an expression of motion is built by means of compositional rules.This study has limited itself to the locative structure Nc Vdp L_Prep Ns, where Nc denotes the moving entity, Vdp a motion verb, L_Prep a spatial preposition, and Ns the locative complement interpreted as a place (sentences corresponding to set phrases or metaphoric structures have not been considered). Finally, only the *passé composé* (present perfect) has been used : its perfectiv aspect allows to avoid the interference of the aspectuality linked to the tense with the one linked to the polarity of the verbs.

2.2. *Semantic classification of motion verbs*

Only motion verbs matching the definition of Boons (1987) have been considered : *"a verb of motion is a verb of movement which implies that a body moves from one place to another without any modification of its form or of its substance during the process"*.

(1) *Jean est arrivé*	John has arrived
(2) *Jean est arrivé à Toulouse*	John has arrived to Toulouse
(3) *Jean est arrivé de Toulouse*	John has arrived from Toulouse

Each verb of motion implicitly suggests a place. In (1), no explicit place is given, but we understand that John arrives somewhere. This implicit place is called the **verbal space of reference, LRV**. When an explicit place (Ns) is present in the expression of motion ((2) and (3)), it is not always in accordance with the LRV. We have a **relation of congruence** when there is accordance, as in (2) : John arrives somewhere, and he really does to Toulouse. Otherwise, we have **not a relation of congruence**, as in (3) : John arrives from somewhere (LRV) which is not Toulouse (Ns).

This examples also show the existence of different polarities. Following Boons, the **aspectual polarity** constitutes a criterion for the classification of motion verbs. A verb is **initial** if it suggests an initial place (*"partir"* (to leave), *"s'éloigner"* (to go away)), **medial** if it suggests a medial place (*"passer"* (to go over), *"courir"* (to run), *"graviter"* (to revolve round)) or **final** if it suggests a final place (*"arriver"* (to arrive), *"s'approcher"* (to approach)).

For some verbs (*"s'éloigner"*, *"s'approcher"*, *"courir"*, *"graviter"*), the moving entity stays during its whole motion on the same side of the LRV. Others (*"partir"*, *"arriver"*, *"passer"*) describe a moving entity which crosses the "frontier" of the LRV, at least one time, during its motion. This difference is used as the second criterion. For the former group we say that there is **no change of space of reference**; for the latter that there is **change of space of reference**.

The third criterion concerns the **relation of localization** of the moving entity w.r.t. the LRV. This relation can be **internal** (*"partir"*, *"arriver"*, *"passer"*, *"courir"*) or **external** (*"s'éloigner"*, *"s'approcher"*, *"graviter"*).

Using these three criteria, the following classification is proposed :

		initial (i)	final (f)	medial (m)
change of space of reference (1)	internal (int)	*partir (to leave)* (i,1,int)	*arriver (to arrive)* (f,1,int)	*passer (par) (to go over)* (m,1,int)
	external (ext)			
no change of space of reference (orientation) (2)	internal (int)			*courir, (to run)* (m,2,int)
	external (ext)	*s'éloigner, (to go away)* (i,2,ext)	*s'approcher, (to approach)* (f,2,ext)	*graviter (to revolve round)* (m,2,ext)

○ : verbal space of reference (LRV)
→ : direction of motion

2.3. *Semantic classification of spatial prepositions*

Prepositions, simple or complex can be separated in two main groups. The first group contains **positional prepositions** since they just describe a relation of localization. According to the criteria of **relation of localization** (§2.2), we can have **internal** (*"dans"* (in)) and **external** (*"en face de"* (in front of)) prepositions. The second group contains **directional prepositions** since, in addition of a relation of localization, they also suggest the direction the moving entity has to use to access[1] the place they introduce. We consequently use for them not only the criterion of **relation of localization** (**interne**; **externe**), but also the criterion of **aspectual polarity (initial; medial; final)**.

The following classification is then proposed :

[1] "access" is used in a broad sense; for initial prepositions, it is really an "access to" the place; for final ones, it is a "leaving of" the place; for medial ones, a "cross of" the place.

		internal (int)	external (ext)
positional		*dans* *(in)* *sur* *(on)*	*en face de* *(in front of)* *derrière* *(behind)*
directional	initial (i)	*de* *(from)* *de chez* *(from at)*	*de derrière* *(from behind)*
	final (f)	*jusqu'à* *(as)*	*vers* *(towards)* *jusque sous* *(as far as under)*
	medial (m)	*par* *(through)*	*autour de* *(round)* *par dessus* *(through above)*

2.4. *Compositional rules between motion verbs and spatial prepositions*

The semantics of expressions of motion is now build using compositional rules and represented in what is called a **type of motion** using the 3 criteria defined in §2.2.

Rule 1 : for the combination of a positional preposition with :

a) a medial or final verb :

the verb determines the aspectual polarity and the change of space of reference of the resulted type of motion;

the preposition determines the relation of localization (see (4))

b) an initial or medial internal verb :

the same as in a), except that the aspectual polarity of the type of motion here is always final (see (5))

Rule 2 : for the combination of a directional preposition with a motion verb :

the verb determines only the change of space of reference;

the preposition determines the aspectual polarity and the relation of localization (see (6)).

(4) *Jean est arrivé à Toulouse* John has arrived to Toulouse

Vdp (F,1,int) + L_Prep (int) => motion (**F,1,int**)

(5) *Jean est sorti dans le jardin*. John has gone out into the garden

Vdp (I,1,int) + L_Prep (int) => motion (**F,1,int**)

(6) *Jean s'est enfui par le jardin* John has run away by the garden

Vdp (I,1,int) + L_Prep (M,1) => motion (**M,1,int**)

(7)*La balle a roulé sous la table* The ball has rolled under the table

Vdp (M,1,int) + L_Prep (ext) => motion (**M,1,ext**) (rule 1-a)

Vdp (M,1,int) + L_Prep (ext) => motion (**F,1,ext**) (rule 1-b)

When we combine a positional preposition with a medial internal verb, both rules 1-a and 1-b can be applied. This reflects the natural double interpretation. In (7), the rule 1-a gives the medial interpretation : the ball is already under the table and stays there during the whole motion. The rule 1-b gives the final interpretation : the ball is not under the table; but its motion is such that it goes (rolling) under the table.

3. A FORMAL REPRESENTATION

3.1 *A two-level semantics*

A type of motion is expressed using the 3 criteria of §2.2. From a pure combinatorial point of view, we obtain 12 different types of motion :

motion (I,1,int)	motion(I,1,ext)	motion(I,2,int)	motion(I,2,ext)
motion (M,1,int)	motion(M,1,ext)	motion(M,2,int)	motion(M,2,ext)
motion (F,1,int)	motion(F,1,ext)	motion(F,2,int)	motion(F,2,ext)

A type of motion is the result of compositional rules (cf. §2.4) between a group of verbs and a group of prepositions. For the French language, there are 7 non-empty groups of verbs and 8 of prepositions. From a pure theoretical combinatorial point of view, this makes 56 different combinations. It is however true that combinations are not generally free in natural languages. For the French language[2], only 34 are in fact linguistically accepted (cf. table in §3.6) We then have only 12 types of motion for representing 34 different combinations. This classification is thus not sufficiently fine : a type of motion groups together motions of different semantics, which in fact differ by the kind of relation which stands between the LRV and the Ns.

To describe more precisely the semantics of expressions of motion, we are led to proceed in two steps : the computation of the type of motion, and the specification of the relation between the LRV and the Ns. One normal temptation could consist in computing these two steps and building a global representation of both steps. We have here chosen another approach. We define a two-level semantics. The **first level**, or **imprecise level**, describes the relations between the moving entity and, respectively, the LRV and the Ns (this corresponds to the type of motion). The **second level**, or **precise level**, includes the first one and makes it fully precise by adding the relation between the LRV and the Ns. We argue that this approach is more fruitful, and we show (§3.7) that we can realize (at least some kinds of) natural inferences using a spatio-temporal reasoning only based on the first level semantics representation. This is an important trump, especially from a computational point of view,

[2]This difference is specific to the French language. Studies on other languages would certainly bring different results, for the number of linguistically accepted combinations and for the number of non-empty groups of verbs and prepositions. But the linguistic framework used here seems well adequate to serve as a common structure for multi-lingual studies and to be at the basis of extremely interesting and fruitful comparative linguistic studies.

where it means that we can perform natural inferences working on a reduced set of relations (w.r.t. the complete set of the precise level), ie. having both a smaller size of handled data and a shorter time of execution of the reasoning processes.

3.2 *A set of markers*

The linguistic study has shown the correlation between the spatial and temporal links between typical places and the spatial and temporal semantics of the expression of motion. Formalizing this semantics then amounts to represent these links formally. We define a set of markers to catch the typical places at the representational level. This allows to treat motion in a more general way and to enonciate rules directly at the level of the markers. The linguistic analysis has shown that places can be introduced in an expression of motion as a LRV[3] or as a Ns, preceded by a spatial preposition[4]. This distinction in fact corresponds to a syntactic one. There also exists a semantic distinction too, between **real places** and **places of reference**, each of them having either an initial, medial or final polarity.

(8)*Jean est passé de la maison dans la rue par le jardin*
John went from the house into the street by the garden

(9)*Paul s´est éloigné de la maison* — Paul has gone away from the house

(10)*Paul a longé le mur* — Paul has gone along the wall

(11)*Paul s´est rapproché de la voiture* — Paul has approached the car

In (8), *"maison"*, *"rue"* and *"jardin"* are a real initial, a real final and a real medial place, respectively. They are the places in which John is at the beginning, the middle and the end of his motion. In (10), the wall is not a real medial place (Paul is not inside it) but rather represents a medial place of reference. Likewise, in (9) and (11) the house and the car represent an initial and a final place of reference. We define 6 markers, for each of these types of places. In (8), we can then match[5] LI and *"maison"*, LM and *"jardin"*, LF and *"rue"*, in (9), RLI and *"maison"*, in (10), RLM and *"mur"*, in (11), RLF and *"voiture"*.

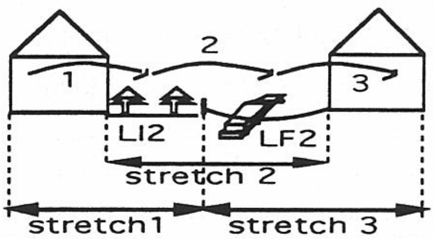
	Initial Aspect	Medial Aspect	Final Aspect
Real Place	LI	LM	LF
Place of reference	RLI	RLM	RLF

[3]Verbs do not in fact introduced themselves directly places, but rather create a kind of intrinsic phenomenon similar to anaphora, which allows to match the LRV (the implicit place suggested by the verb) with a place introduced previously or further in the analysed discourse or with a context-dependent place.
[4]Other means are of course possible. For example as a direct object : *"traverser la rivière"* ("to cross the river"). This, however, does not belong to the syntactic domain covered by the linguistic study of Laur.
[5]The matching is here presented in a non-formal way. We are in fact able to perform it automatically from the calculation of the type of the corresponding motion and the application of representational rules (cf. §3.6).

(12)*Jean est sur la pelouse. Il entre dans la maison. Maintenant il est dans la maison*
John is on the lawn. He enters into the house. Now he is in the house

(13)*Jean sort de la maison dans le jardin. Puis il passe dans la rue et rentre chez l'épicier*
John goes out of the house into the garden. Then he goes into the street and enters the grocer's

In fact, our markers catch the spatial aspect of the places, but also their temporal aspect, corresponding to the role they play during the motion. We would like to discuss more this point. When people talk about the duration of a motion, they generally refer to what we will here call the **normal duration**. By normal duration, we understand the temporal length which begins when the motion starts and which ends when the motion finishes. When a motion is surrounded by states (12), the distinction of static and dynamic phases allows an easy determination of both boundaries (start and end) of the normal duration. When several motions are following each other (13), this becomes difficult (as for *"Puis il passe dans la rue"*). We then define another duration : the **global duration.** It starts when the moving entity enters the real initial place (LI), and finishes when it goes out of the real final place (LF). It includes the normal duration and also as in (12), surrounding states. For the second motion of (13), *"jardin"* is associated with LI2 *"rue"* with LF2. We can then precisely define its global duration (noted *stretch2*). We thus define in a simple way a global duration for each motion.



With this definition, we obtain an overlap of the global durations of following motions, even if they are separated by many states, since states are included in global durations. We would like to point out the advantage of such a result : it insures the spatial and temporal continuity of entities occuring in successive motions. This constitutes a primordial prerequisite to the realization of inferences (cf. §3.7).

Finally, we define 3 new markers, purely temporal, from the definition of the global duration : **ti**, **tm** and **tf**, which represent the temporal length during which the moving entity is inside the real initial (LI), real medial (LM) and real final (LF) place, respectively.

3.3 *Motivations for an adequate formalism*

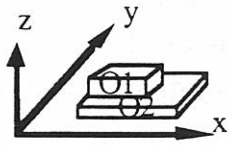
The six markers (LI, LM, LF, RLI, RLM and RLF) are used to catch at the representational level the typical places brought out at the linguistic level. To represent spatial and temporal links between these places, we need a set of formal relations to be applied between our markers. The formalism we are looking for has to provide us with an adequate set of relations (ie. allowing us to represent between our markers the links revealed at the linguistic level between the typical places), but also to be based on an ontology suitable to human beings´ conceptualization of space, time and motion. Recent studies have shown that cognitive concepts about space and time are qualitative in nature. Others have revealed that space, as it is described by natural languages, is a relational space, but also a space strongly linked to time (cf. Vieu (1991) and Aurnague (1991)). A spatial relation between two entities is taken at a given moment, identical for both entities. Therefore, human beings model cognitive spatial concepts by relational representations of the relationships between spatial entities. However, they consider these entities in a way different from a pure spatial way, in order to take into account also the temporal component which is linked to them. Thus, we are interested in the way to formalize spatial cognitive concepts as they are revealed by natural language, ie. by also considering their temporal dimension. Unlike the study of the semantics of time, for the formal semantics of space, traditional theoretical frameworks do not exist. In the following, we present and discuss some of the most important existing formalisms.

The most important and well known formalism, which has influenced many other works, is the qualitative representation of time of Allen (1985). It is a time theory based on a structure of intervals from a unique primitive relation : MEET. From this primitive, twelve other relations are defined, such that the link between any two temporal intervals can always be described by one of these relations or a disjonction of them.

relation	définition	abréviation	inverse	exemple
I meets J	< *relation primitive* >	m	mi	I J
I before J	$\exists$ K / I m K m J	<	>	I J
I equal J	$\exists$ K,L / (K m I m L) $\wedge$ (K m J m L)	=	=	I J
I overlaps J	$\exists$ A,B,C,D,E / (A m I m D m E) $\wedge$ (A m B m J m E) $\wedge$ (B m C m D)	o	oi	I J
I starts J	$\exists$ A,B,C / (A m I m B m C) $\wedge$ (A m J m C)	s	si	I J
I finishes J	$\exists$ A,B,C / (Am B m I m C) $\wedge$ (A m J m C)	f	fi	I J
I during J	$\exists$ A,B,C,D / (A m B m I m C m D) $\wedge$(A m J m D)	d	di	I J

In order to generalize this system to space, some studies have been realized, for example the one of Güsgen (1990). The key idea of this work is to split spatial and temporal relationships between objects into components : left/right; front/rear; above/below; before/after. From the relations of Allen, he defines four basic relations. He then represents relationships between two objects by means of (set of) tuples of basic relations.

relationship	symbol	symbol for	picture
O1 left of O2	<	>	O1 O2
O1 attached to O2	≤	≥	O1 O2
O1 overlapping O2	<=	=>	O1 O2
O1 inside O2	⊏	⊐	O1 O2



O1 (⊏, ⊐, ≽) O2

In fact, this is not a cognitive representational system. Human beings do not describe spatial relationships by using cartesian tuples of relations, each describing the link between intervals on one of the three axes. In addition, this system can only treat parallelepipeds, all oriented in the same way, and cannot take into account intrinsic interpretations, commonly used in natural language. We are obviously looking for a more cognitive formalism. But the formalization of cognitive concepts about space seems really difficult and complex. Before going further, we would like to discuss what looks like human beings´ conceptualization of space. We try, in the three following points, to give some elements of an answer.

Firstly, it seems that space is regarded as a whole. Indeed, if some prepositions like "on" or "in front of", show that human beings use natural referential axis (axis of gravity in the case of "on") or artificial referential axis, built from referential objects (as for "in front of"), other prepositions, such as "near", "close to", clearly show that human beings have the faculty to describe space without using any referential axis, ie. considering space simply as a whole.

Secondly, it seems that space is filled up by objects considered as basic entities. We commonly speak about things like "the book is on the table" without specifying (and even often without knowing) more about these objects. In particular their precise shape (the book can be open or closed), their (relative) size, their structure (the table can have a leg missing). That means that we cannot assume basic smaller elements (such as the well-known "points") to be used by compositional arrangements to build the objects we refer to.

Thirdly, it seems, from all we have said before, that space is described by expressing qualitative relationships directly between spatial entities.

Studies in this direction are nevertheless not new, since Aristotle already studied in the IVth century BC the part-whole relationships. The first formalisation, by another means than the Set Theory, is only appeared in 1927-1931, due to Lesniewski, under the name of Mereology. Mereology can be characterized by the three following important points :

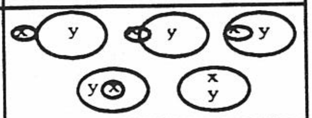
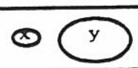
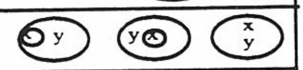
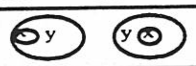
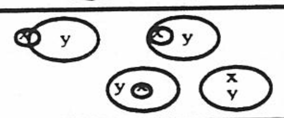
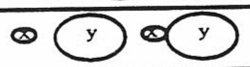
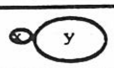
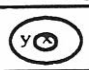
* it refuses the existence of individuals of an higher-order, and, in particular, the existence of the null-element (the equivalent of the empty set in the Set Theory);
* it is not based on a prerequisite Euclidian space, but on a space built by the entities and their interrelations as they are introduced;
* its basic elements are not the traditional points but (spatio-temporal) individuals.

The first point clearly matches the cognitive conceptualization of space and time. The second one furnishes a good background for qualitative representations. The last one answers our request on the description of space by means of qualitative relationships directly between spatial entities, which are considered as basic elements. But it also allows for basic elements of the system not only spatial entities but also spatio-temporal individuals, as defined in naïve physics by Hayes (1978). We have seen that space is strongly linked to time and that we would like to formalize spatial cognitive concepts by also considering their temporal dimension. It is now entirely possible in the framework of the Mereology.

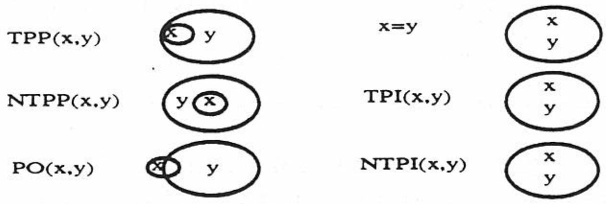
Several more or less equivalent systems have been defined (Tarski 1937; Leonard & Goodman 1940; Lesniewski 1919-1929; Clarke 1981-1985). The one of Clarke seems to be the best for our work. In the next paragraph, we present it and discuss what distinguishes it from the other versions and why we have chosen to use it.

3.4. *The qualitative representation of space-time of Clarke*

From the primitive relation of connexion (C), Clarke (1981) defines 8 other relations.

relation	name	definition	exemple
C(x,y)	connects with	< relation primitive >	
DC(x,y)	disconnected from	$\neg$ C(x,y)	
P(x,y)	part of	$\forall$z. [C(z,x)$\rightarrow$C(z,y)]	
PP(x,y)	proper part of	P(x,y) $\wedge\neg$ P(y,x)	
O(x,y)	overlaps	$\exists$z. [P(z,x)$\wedge$P(z,y)]	
DR(x,y)	discrete from	$\neg$ O(x,y)	
EC(x,y)	externally connected to	C(x,y) $\wedge\neg$ O(x,y)	
TP(x,y)	tangential part of	P(x,y) $\wedge$ $\exists$z. [EC(z,x)$\wedge$EC(z,y)]	
NTP(x,y)	nontangential part of	P(x,y) $\wedge$ $\neg\exists$z. [EC(z,x)$\wedge$EC(z,y)]	

The system of Clarke is distinguishable from other versions of Mereology on the following points. Clarke dropped Whitehead´s assumption that individuals must be continuous and extends Whitehead´s theory, which dealed with only mereological aspects, by introducing quasi-boolean[6] and quasi-topological[7] operators. The most consequent difference is the choice of C as primitive relation. This allows him to establish a distinction between the overlap (O) and the connection relation (C), which leads to the emergence of a new relation, a relation of external connection (EC). This relation turns to be of highest interest. With it, Clarke can ever since build a quasi-topology (1981) before defining the notion of point (1985). This give to his system a strong cognitive dimension. It is indeed very suitable to the way human beings conceptualize space. A point alone does not exist in space and we cannot refered it directly in natural language. When we want to talk about a particular point, we must use a set of concrete entities to construct it. For example, we can point a finger and say "the point at the end of my finger", or use referential entities like in "the corner of the table" (cf. Vieu 1991). As natural language reflects it, human beings construct points from entities (that means a point is defined by a set of entities) and do not conceptualize entities as set of points. Clarke (1985) reconstructs the notion of point, by means of filter´s methods[8], as set of entities. This system is consequently the most adequate formalism for our work. Just before using it, we would like to introduce six new relations that have been defined by Randell & Cohn (1989) in order to obtain a set of relations with a lattice structure.



3.5. ***Some extensions of the system of Clarke.***

(14)*Jean entre dans la pièce*	John goes into the room
(15)*Jean sort de la pièce*	John goes out of the room

Although the system of Clarke is the best formalism we have found for our work, it is unfortunately not completely adequate, and, consequently, needs some modifications. The problem is that the difference between a spatio-temporal individual corresponding to a static[9] object and one corresponding to a dynamic one, cannot be represented in the present version of the system of Clarke. Let us use (14) and (15) as an illustration of this. Let J and P be the

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[6]"quasi-boolean" because there is no null element, in the pure tradition of Mereology.
[7]"quasi-topological" because there is neither a null element, nor boundary elements.
[8]This is equivalent to the construction of instants from events for temporal theories (Kamp 1979; Bras 1990).
[9]One can object that any object can always be regarded as dynamic, if we choose for this an adequate referential. But the problem remains with now relative dynamicity of one object w.r.t one another.

spatio-temporal individuals corresponding to *"Jean"* and *"pièce"*, restricted to the global length of the motion in which they occur. In (14), John is outside the room during the initial phase of his motion, then enters it during the medial phase, for being inside in the final phase. The link between J and P is here a "partially overlaps" link, and, using the relations of Clarke[10], we write : PO(J,P) or also PO(P,J), since PO is a symmetrical relation. In (15), John is inside the room during the initial phase of his motion, then goes out during the medial phase, for being outside in the final phase. Here again, the link between J and P is a "partially overlaps" relation, and we write : PO(J,P) or also PO(P,J). We then describe by the same relation two motions which have different semantics. We are not able to differenciate the direction of the motion of John w.r.t. the "static" entity (*"pièce"*). Something more is necessary in the formalism of Clarke to realize this. A precedence order between two spatio-temporal individuals w.r.t. a given motion could allow to represent the relative direction of the motion of one of the entities. This order will of course be a partial order, because of its strong dependence on the motion we consider. It will in fact represent the "relative direction" of the motion in the space-time; it will reflect its proper temporality. Clarke (1985) defined a basic temporal relation, the relation B, where B(x,y) means "x is wholly before y", based on an unique linear time, common to all the individuals. Unfortunately our precedence order is partial and based on the proper time of the considered motion. We then propose to introduce a new relation of partial spatio-temporal order, the primitive[11] relation BST, where BST(x,y) means "x is spatio-temporally before y". We will here, by lack of place, only present a discursive definition of this relation.

> **BST(x,y)** <u>means</u> : there is a motion d such that d affects both spatio-temporal individuals x and y, and such that the direction (in the spatio-temporal meaning) of d goes from x to y.

We can explain and illustrate this definition through our examples (14) and (15). In both cases, J and P are affected by the motion of John. For (14), we can, in an unformal way, say that J converges to P (the direction of the motion of John goes towards the room). We can then apply our new relation : BST(J,P). In (15), J diverges from P (the direction of the motion goes away from the room). We here obtain : BST (P,J). We then have two different relations for (14) and (15). This is nevertheless not completely sufficient because we have lost the fact

[10]We now consider under the name "relations of Clarke" the relations really defined by Clarke and the six one added by Randell & Cohn (cf. §3.4).

[11]In fact, BST can be defined (cf. Sablayrolles 1991) from syntactic functions (like *initial_loc(x)*, *verbal_category* ...) and from functions associated to our markers (as *LI(x)*, *ti* ..., for example).

that a "partially overlaps" link stands between J and P. We then define a new relation, BPO, where BPO(x,y) means "x is spatio-temporally before and partially overlaps y" :

BPO (x,y) =def BST (x,y) ^ PO (x,y)
"x is spatio-temporally before and partially overlaps y"

We finally have for (14) both BST(J,P) and PO(J,P), ie. BPO(J,P) and for (15) both BST(P,J) and PO(P,J), ie. BPO(P,J). We can likewise redefine all the relations of Clarke for which this problem occurs (ie. all symmetrical and non reflexive relations). However, it seems not useful to redefine all of them, because of the lattice structure. Six can be adopted as basic, mutually exclusive, relations. Namely, DC ("disconnected from"), EC ("externally connected to"), = ("identical with"), PO ("partially overlaps"), NTPP ("nontangential proper part") and TPP ("tangential proper part"). The relations DC and EC are symmetrical and present the same problem as PO. We consequently redefine them as :

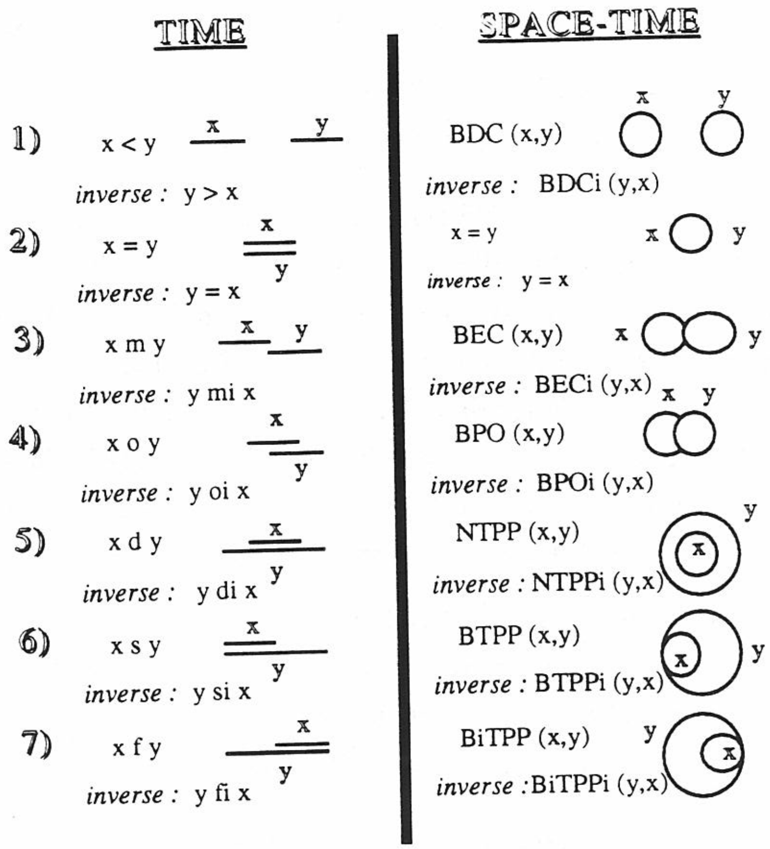
BDC (x,y) =def BST (x,y) ^ DC (x,y)
"x is spatio-temporally before and disconnected from y"
BEC (x,y) =def BST (x,y) ^ EC (x,y)
"x is spatio-temporally before and externally connected to y"

The identical relation, symmetrical but also reflexive, presents no problem since an individual cannot have a motion relativ to himself. We have already redefine the relation PO as BPO. The relation NTPP is asymmetrical and consequently raises no problem. At least, the relation TPP is perhaps the most complex and needs to be refined in two new relations (cf. Sablayrolles 1991, for a detailed illustration) :

BTPP (x,y) =def BST (x,y) ^ TPP (x,y)
"x is spatio-temporally before and a tangential proper part of y"
BiTPP (x,y) =def BST (y,x) ^ TPP (x,y)
"y is spatio-temporally before x and x is a tangential proper part of y"

We have thus built a set of 13 spatio-temporal relations : BDC, BEC, =, BPO, NTPP, BTPP and BiTPP, with their reciprocal relations : BDCi, BECi, =, BPOi, NTPPi, BTPPi and BiTPPi, (see right part of the table below for a graphical illustration), allowing us to describe all the possible links between two spatio-temporal individuals in the framework of motion.

In the following table, we show an analogy between the temporal relations of Allen (which are applied between 1-dimensional temporal entities), and our set of spatio-temporal relations (which are applied between 4-dimensional spatio-temporal individuals). We can easily observe on this graphical illustration that the two sets of relations present strong similarities.



This is the result of the fact that, from a formal point of view, we conceptualize 4-dimensional spatio-temporal individuals as simple 1-dimensional entities, but without loosing any of their spatial and temporal properties, since this 1-dimensionality in fact corresponds to the axis[12] in the space-time which supports the direction of the motion of this individual[13].

3.6. *Formal representation*

We introduce representational rules to build the two level semantics.

We firstly present the rules for the first level, or imprecise level, which describes the relations between the moving entity and, respectively, the Ns and the LRV. We then need two relations. The first one depends on the value of the polarity criterion (I, M or F) and of the criterion of the relation of localization (int or ext) of the type of motion. The second relation depends on the value of the criterion of change or non change of space of reference (1 or 2) of the type of motion and of the value of the polarity criterion (I, M or F) of the verb involved.

<u>criteria 1 and 3</u> :

Iint : BiTPP (slice (cible, ti), LI)[14]

---

[12]Here, "axis" has not to be understood as a whole straight line, but as a curve, in the space-time, following (in space and in time) the motion of the moving entity.

[13]In the case of static individuals, this "axis" in fact is identical with the time axis.

[14]"slice (x,y)" is a function which returns the spatio-temporal individual x which temporal length has been restricted to the one denoted by y; "cible" has to be matched with the moving entity.

Iext: BDCi (slice (cible, ti), RLI)

Mint : [BiTPP (slice (cible, tm), LM) ^ BTPP (slice (cible, tm), LM)] v NTPP (slice (cible, tm), LM)

Mext : [BDC (slice (cible, tm), RLM) ^ BDCi (slice (cible, tm), RLM)] v [BEC (slice (cible, tm), RLM) ^ BECi (slice (cible, tm), RLM)]

Fint : BTPP (slice (cible, tf), LF)

Fext : BDC (slice (cible, tf), RLF)

<u>criterion 2 + category (I/M/F) of the verb</u> :

1 + verb I : BiTPP (slice (cible, ti), LI)

1 + verb M : BiTPP (slice (cible, tm), LM) ^ BTPP (slice (cible, tm), LM)

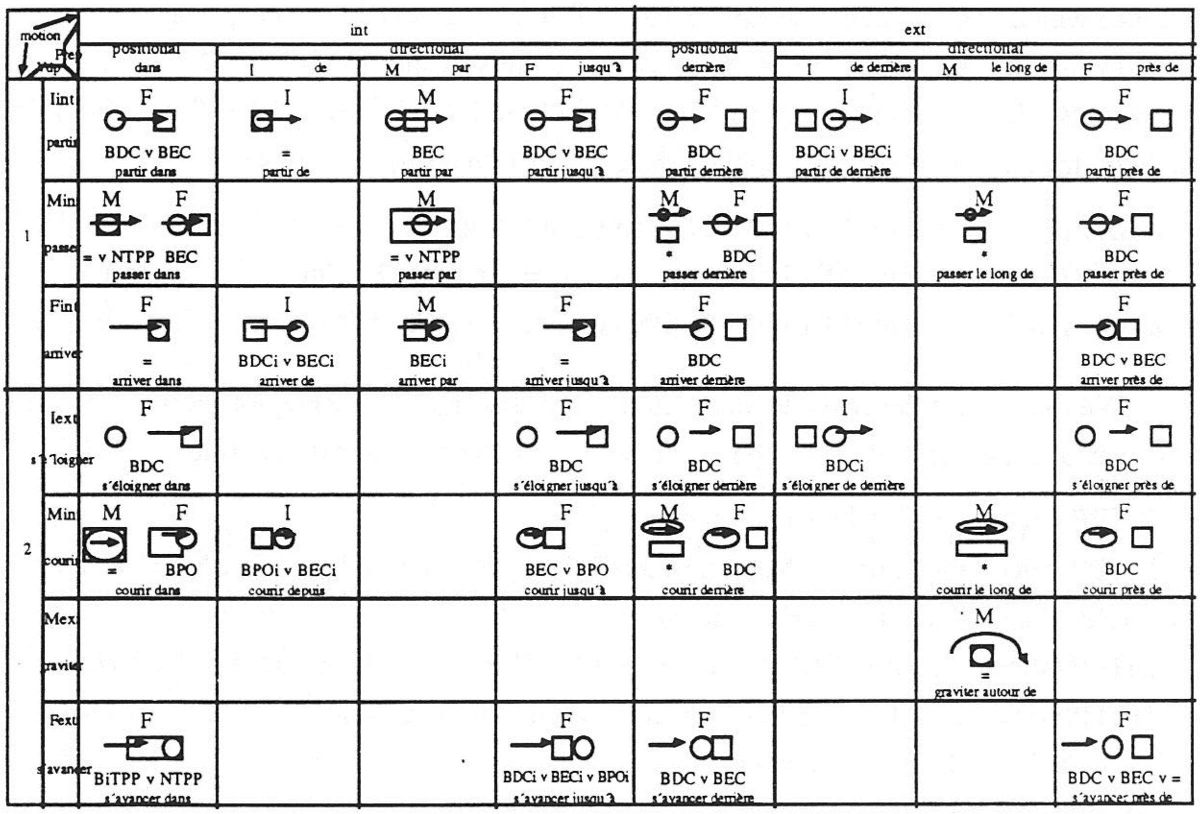
1 + verb F : BTPP (slice (cible, tf), LF)

2 + verb I : BDCi (slice (cible, ti), RLI)

2 + verb M : [BDC (slice (cible, tm), RLM) ^ BDCi (slice (cible, tm), RLM]
v NTPP (slice (cible, tm), LM)

2 + verb F : BDC (slice (cible, tf), RLF)

We then present the rules for the second level semantics, or precise level. At this level, we make the first one fully precise by adding the relation between the LRV and the Ns.



* : {BDC ^ BDCi} v {BEC ^ BECi}

The table represents in its columns the groups of spatial prepositions and in its rows the groups of motion verbs. One box represents an expression of motion, obtained by the combination of a verb of the row and a preposition of the column, belonging to the type of motion which criterion of polarity is written at its top (I, M, F), which criterion of change or non change of space of reference is given by the row and which criterion of relation of localization is given by the column. In each box, a graphical illustration, with a circle standing for the LRV, a square for the Ns and an arrow for the motion of the moving entity, is proposed. An example in natural language is also given. At least, the relation (or a disjonction of relations) standing between LRV and Ns is precised. Empty boxes correspond to non linguistically acceptable combinations (in the French language).

3.7. *Some possibilities of natural spatio-temporal reasoning*

(16)*Jean est passé du jardin dans la maison par la terrace. Puis Jean est sorti de la maison dans la rue.*

John went from the garden into the house by the terrace. Then John went out of the house into the street.

We propose, as an example of the possibilities of reasoning on our representations, the inference which consists to condense the text (16) in one sentence (ie. one global motion).

In the first sentence, the verb *"passer"* belongs to the group Vdp (M,1,int) and the prepositions *"du"* (which is a contraction of *"de le"*) to L_Prep (I,int), *"dans"* to L_Prep (int) and *"par"* to L_Prep (M,int). We applied the compositional rules (cf. §2.4) :

"passer du"	: Vdp (M,1,int) + L_Prep (I,int) => motion (I,1,int)	(a)
"passer dans"	: Vdp (M,1,int) + L_Prep (int) => motion (F,1,int)	(b)
"passer par"	: Vdp (M,1,int) + L_Prep (M,int) => motion (M,1,int)	(c)

We then select the two adequate relations of the first level semantics corresponding to the values of the criteria of each type of motion, using the representational rules (cf. §3.6) :

(a) BiTPP (slice (cible1, ti1), LI1=*"jardin"*)
BiTPP (slice(cible1, tm1),LM1=*"terrasse"*) ^ BTPP (slice(cible1,tm1),LM1=*"terrasse"*)

(b) BTPP (slice (cible1, tf1), LF1=*"maison"*)
BiTPP (slice(cible1,tm1),LM1=*"terrasse"*) ^ BTPP (slice(cible1,tm1),LM1=*"terrasse"*)

(c) {BiTPP (slice(cible1,tm1),LM1=*"terrasse"*) ^ BTPP(slice(cible1,tm1),LM1=*"terrasse"*)}
v NTPP (slice (cible1, tm1), LM1=*"terrace"*)
BiTPP (slice(cible1,tm1),LM1=*"terrasse"*) ^ BTPP (slice(cible1,tm1),LM1=*"terrasse"*)

The disjunction in the first relation of (c) corresponds to the double interpretation of medial and internal verbs (cf. §2.4). It is here easily solved with the second relation, which is equal to the first part of the disjunction. This verb and its three prepositions in fact describe a same motion; we then group (a), (b) and (c) as a conjunction of relations. We obtain :

(d) BiTPP (slice (cible1, ti1), LI1=*"jardin"*)
BiTPP (slice(cible1,tm1),LM1=*"terrasse"*) ^ BTPP (slice(cible1,tm1),LM1=*"terrasse"*)
BTPP (slice (cible1, tf1), LF1=*"maison"*)

For the second sentence, we proceed likewise and obtain (e) and (f), groupped in (g) :

"sortir de"	BiTPP (slice (cible2, ti2), LI2=*"maison"*)	
	BiTPP (slice (cible2, ti2), LI2=*"maison"*)	(e)
"sortir dans"	BTPP (slice (cible2, tf2), LF2=*"rue"*)	
	BiTPP (slice (cible2, ti2), LI2=*"maison"*)	(f)

(g) BiTPP (slice (cible2, ti2), LI2=*"maison"*)
BTPP (slice (cible2, tf2), LF2=*"rue"*)

With the only knowledge of this little text, and with the presence of the adverb *"puis"*, we suppose these two motions successive motions without any other in between. Here, there is an overlap of their global durations[15] which is such that (from its definition) tf1=ti2, ie. the final phase of the first motion temporally coincides with the initial phase of the second. This insures the spatio-temporal continuity of *"Jean"* and *"maison"*, which allows us to write down the equalities : cible1=cible2 and LF1=LI2. If we apply this to (d) and (g), we have :

(h) BiTPP (slice (cible1, ti1), LI1=*"jardin"*)
BiTPP (slice(cible1,tm1),LM1=*"terrasse"*) ^ BTPP (slice(cible1,tm1),LM1=*"terrasse"*)
BTPP (slice (cible1=cible2, tf1=ti2), LF1=LI2=*"maison"*)
BiTPP (slice (cible2=cible1, ti2=tf1), LI2=LF1=*"maison"*)
BTPP (slice (cible2, tf2), LF2=*"rue"*)

Let us just use in (h) the number 3 to denote the inferred representation, and lay down the following affectations : cible3=cible1=cible2; LI3=LI1; LM3=LM1+LF1; LF3=LF2.

(i) BiTPP (slice (cible3, ti3), LI3=*"jardin"*)
BTPP (slice (cible3, tf3), LF3=*"rue"*)
{BiTPP (slice (cible3, tm3), LM3=*"terrasse et maison"*) ^
BTPP (slice(cible3,tm3),LM3=*"terrasse et maison"*) }

[15]Here, we can remark that with the concept of normal duration, we would only have that the normal duration of the first motion precedes or meets (to use Allen´s terminology) the normal duration of the second.

We recognize in (i) the description of a motion expressed in natural language by a verb Vdp (M,1,int), and three prepositions : one, L_Prep (I,int) associated to the place *"jardin"*; one, L_Prep (int) to the union of places *"terrasse et jardin"*; and one, L_Prep (M,int) to *"rue"*. In order to present this result under a natural language form, let us choose in the groups we have just found a verb and three prepositions. We then obtain the following sentence :

(17)*Jean est passé du jardin dans la rue par la terrasse et la maison.*
John went from the garden into the street by the terrace and the house.

This result is plainly in accordance with what human beings would infer about our little text (16). However, this is just an example of spatio-temporal reasoning that can be done on our representations. We would like to study soon this inferential level more deeply.

4. CONCLUSION

This work constitutes the pursuit of complementary collaborations of linguistic and formal studies of the semantics of natural language, started some years ago at Toulouse. This interdisciplinary approach, in the case of the study of expressions of motion, is however only at its beginning. We propose some interesting extensions that we would like to investigate. Firstly, the integration of agents and intentionality seems to be promissing. Another important extensions concerns the spatio-temporal reasoning. Two frameworks seem interesting. A crucial problem is the determination of the temporal validity of our spatio-temporal relations. The event calculus (Kowalski & Sergot 1986) satisfies two basic constraints of this problem : the underlying default logic is well adapted to the non-monotony of the deductions; and the temporal structures of the "event calculus" are closely associated to non-temporal knowledge. This part of the research is developped by Bernard, Borillo M. and Gaume (1990 ; 1991). The second is the DRT developed by Kamp (1979). We have seen in §3.7 that spatio-temporal reasoning also requires to deal with discourse. Bras (1990) has developed inside the DRT framework a calculus of the temporal structures of a French discourse. Recent works on DRT have also shown the necessity of the introduction of inferential mechanisms, triggered by some linguistic forms, to interpret discourse (Asher and Lascarides 1991). We would like to study how these different components can all be associated and work together in the DRT framework. The last important extension concerns the formalism of Clarke. We would like to associate the modifications we have made to topological and functional extensions already done by Vieu (1991) and Aurnague (1991), and also close to natural language preoccupations. An implementation of this whole system is planned in the framework of the project VILAIN (VIsion and LAnguage INtegration) developped in the group of Toulouse (Aurnague, Borillo, Sablayrolles). It deals with construction and description of graphical scenes using natural language (spatial places and motions).

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Some problems about hybrid symbolic representations based on French motion verbs

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1 Introduction

This text is a shortened version of [3].The problem I address there is that of devising a prototype for a computer–assisted archiving system, which would be used to store some suitable representation of traffic accidents. Basically, these representations are constructed from the accident declarations, written by the driver(s) after an accident (they are called *constats amiables* in French). I shall not study the archiving task itself (operations available to the user, graphic interface, etc.), but only some of the formal aspects involved in the representations. In the present text, I shall try to give a flavour of the main representational problems, without aiming at exhaustiveness or technical accuracy.

2 The archiving task

At a general level it is very simple. The user must declare a sequence of canned phrases, which mention the positions and motions of vehicles. Six kinds of informations are considered: environment shape(s) (roads, streets, crossroads, etc.), signs and legal regulations (traffic lights, one–way paths, etc.), positions and motions of vehicles, actions, perceptions, and intentions of drivers, temporal relations between situations.
As an example, look at the original French text below, and its English (clumsy) adaptation:

Je circulais à environ 45 km/h dans une petite rue à sens unique où stationnaient des voitures de chaque côté. Surgissant brusquement de ma droite sortant d'un parking le véhicule de Mme Glorieux était à très peu de distance de mon véhicule; le passage étant impossible: surpris, je freinais immédiatement mais le choc fut inévitable.

I was driving at about 45 km/h in a narrow one–way street with cars standing on each side. Popping out of a parking on my right Mme Glorieux's car was very close to mine; no passage being possible: I was surprised and braked right away but it was not possible to avoid the collision.

[1] I want to thank Gerd Herzog which pointed out to me very valuable work carried out in Germany on similar topics.

I will refer to this text simply as "the text" in what follows.
While superficially simple, the text exhibits the two main (interconnected) problems one encounters in this domain. It is vague and it is ambiguous. Most texts of this type are vague because geometric and cinematic information is very sketchy. It is often necessary to use abductive reasoning to "deduce" the circumstances of the accident. Moreover some indications are ambiguous. E.g. we are told that "no passage was possible", but for whom? Fortunately, accident declarations use other sources of information (drawings, questions lists) to compensate for the poor informational quality of the texts. However, in some cases, significant ambiguities remain and may influence the judgments of experts. Moreover some consistency checks between the text and the other parts of the declarations are necessary. A prototype for archiving should demonstrate two basic abilities:
- an elementary mastering of abduction,
- an understanding of causal relationships in the domain of car accidents.
I will consider the second problem in this paper, because the first is much more general and, to a large extent, not relevant to our application domain.

3 French motion verbs

3.1 General categories

Intuitively, one can recognize in French several classes of motion verbs:

- positional verbs (e.g. *arriver* ≈ *to arrive*, *sortir* ≈ *to go out*,...),
- authentic motion shape verbs (e.g. *zigzaguer* ≈ *to zigzag*, *onduler* ≈ *to wave*, ...),
- weak motion shape verbs (e.g *se déporter* ≈ *to go off the path, to drift. tourner (à droite)* ≈ *to turn (to right)*, ...),
- rate verbs (e.g. *accélérer* ≈ *to speed up*),
- others (having to do with intentional aspects or container shape for instance).

3.2 Shape motion verbs

There is only a handful of verbs which "describe" motion shape, e.g. *louvoyer*, *zigzaguer*, *spiraler*, *serpenter*, *onduler*, *faire un(des) cercle(s)*, *faire des méandres*, as well as <motion verb> *en* <shape noun> constructs, like *courir en rond* or *marcher en zigzag*. I call verbs in this class *strong* motion shape verbs, because they tend to suggest well–defined motion shapes.

3.3 relative positions verbs and weak motion shape verbs

Many verbs, e.g. *arriver* or *partir*, give information on the successive positions of a moving object ([4, 7]). Some of them impose contraints on the relative trajectories of two objects (*dépasser*), or on different trajectories of the same object in time (*se déporter*). In the latter case I speak of *weak* motions shape verbs, because the verb provides only general constraints as to the form of the motion. While they are "weak", these verbs are different from simple positional verbs, from which no constraint on shape can be extracted. We might consider for instance the following verbs or expressions: *appuyer, bifurquer, chasser, contourner, couper la route à, se déporter, dévier, doubler, éviter, faire une queue de poisson à, faire un tête à queue, obliquer, se mettre en travers, se rabattre, redresser, serrer, tourner.*
Since these verbs do not *describe* shapes (in contradistinction with strong verbs like *zigzaguer*), it is important to know exactly what they do. My intuition is that they impose constraints on successive trajectories of a moving object. If these constraints bore on just positions, our so called motion shape verbs would reduce to positional verbs, like *arriver* or *partir*.

4 Basic tools

4.1 General constraints on format

We use only bi–dimensional representations, which could, in principle, be associated with drawings on a computer screen. This implies that we ignore factors connected with slopes, differences in heights, and so on.

4.2 Orientations and directions

For defining directions I use four orientations: front, back, right, left. When no precision is added, *front* correspond to the upper part of the screen, *back* to the lower part, *left* and *right* having their usual meanings. A family of directions is just an ordered pair of orientations, e.g. `fl` (for front–left) or `br` (for back–right). "Pure" directions like front, back, left, and right are simply defined to be `f0`, etc. Obviously, we need to represent changes in directions within some given family, or changes from some family to another.

4.3 segments and zones

To define basic shapes we use *segments* which are finite portions of straight or curved lines. Any segment has two endpoints (an origin and an end) and a length. The regions and moving objects are rectangles, parallelograms, or

curved rectangles (portions of crown). All of them have widths, lengths, and, in the case of curved rectangles, some curvature. It is important to note that, in most cases, we need not handle detailed information about segments. In effect, we may consider zones as narrow lines, which alleviates the treatment. I use the notion of *relevant zone* (rz). A rz is a bi-dimensional area whose properties are relevant to the analysis of motion. Formally, it is an object with a finite number of atributes, namely:
- a backbone (a path) which connects its back to its front,
- geometrical measure attributes (length, width, curvature),
- direction(s),
- legal constraints,
- neighbouring relevant zones.

The backbone is relative to the granularity of the representation, that is it is not possible to obtain a more fine–grained decomposition of the rz axis, unless one changes the overall granularity. Normally, we need not know the exact granularity, since we are in a symbolic system, but we need some general constraints. When the rz is rectilinear it has a constant direction. When it has some non null curvature it gets a set of directions.

4.4 Places, paths, directions

A path will be just a sequence of places $< l_0 \ldots l_n >$. Unless stated otherwise the places in a path will be points. When I say that an object is *at* some place, I mean that the center of the object occupies the point.
To each pair of successive points in a path we can associate a unique direction wrt some orientation standpoint. When this standpoint has been fixed `dir(X,Y,D)` expresses the fact that `D` is the direction associated with the points `X` and `Y`. When an object *follows* a path it occupies the elements of the path in the order which defines the path, and not in another order.
If paths and rz's were independent, this would result in very complex motions. Looking at the text, it is obvious that we need not make separate unrelated declarations for zones and paths, because this would cause some unwanted redundancies. We may declare a zone, in which the writer's car moves at a constant distance from each side. This the normal (default) motion in a rz. We said in the last section that any rz had a backbone, which is a path. It is usually a good idea to declare rz's which correspond to "lanes" on roads.

4.5 Vehicles

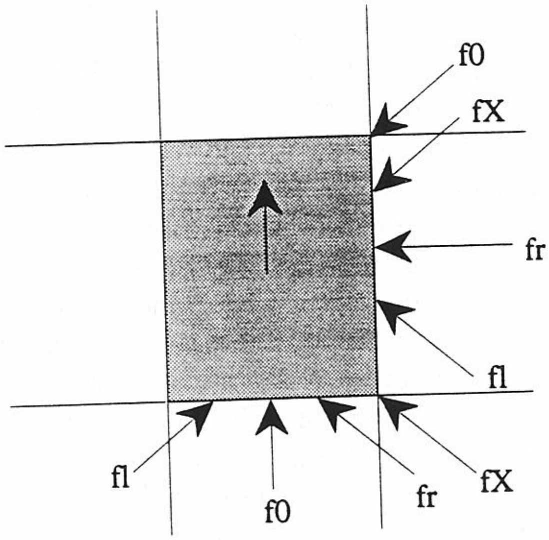
Like a rz, our moving objects (vehicles) will have just four sides. These sides are determined wrt intrinsic orientation, which, by convention, is associated with the object center.At each moment a moving object can be inside a rz

or cross some side of a rz. To take into account .position changes, it seems necessary to use a distance operator, which should minimally return some rough evaluation of a quantity for a pair <point,line>. I will suppose that distance degrees can be ≥ 0, but also that there is a designated degree,say $0\star$ which corresponds to spatial "meeting" (in Allen's sense for temporal intervals).The essential notion is that of *room*: when some object occupies some place in a rz, or at the frontier between two zones, how are we to describe the room it leaves for other objects? I retained the standard idea of proximity rectangles (familiar to PostScript users), according to which a polygon can be enclosed in a minimum–size rectangle for current spatial operations (see [8] for a clear illustration). When an object is considered to parallel the backbone of a rz (default case), its proximity rectangle is just a rectangle whose center is located at the center of the object, and whose dimensions are the object dimensions. In case of a rotation, the proximity rectangle is widened and shortened at the same time.
Of course, the main question us: is there enough room for another object to move without collision?

4.6 Positions and crashes

In many declarations an accident takes the form of a vehicle hitting another vehicle. A geometrical qualitative system cannot in general be used because we have simply not enough information. Moreover, such a system, even in the most favourable cases, would spend much time to deduce things which are considered as obvious by persons who have only a layman knowledge about traffic accidents. In fact the traffic problems involve *case–based reasoning* ([6]), that is the mastering of a finite set of standard situations, which hold repeatedly and constitute the standard backgrounds for accidents.
However, behind the variety of cases, there is one simple geometrical principle: the parts which collide are always the part which are mutually nearer at the moment of the accident. So the "reasoning" amounts to identify the possible parts which follow this principle. Fig. 1 shows different possible positions during a collision. The letters refer to the parts of vehicles outlines: for instance fr designates the front right angle of the vehicle, f0 designates the front, fX designates any front part.

Figure 1



According to the information of the text, it is not possible for the vehicle of Mme Glorieux to hit the writer's vehicle at the rear with its front left angle. This would entail that Mme Glorieux's car is coming from the left, which is excluded by the text. It is easy to list triples of indications (relative direction of the hitting vehicle, hitting part, hit part), and to use it to check the consistency of declarations.

5 Time and dependences

I will illustrate the mixing–up of general reasoning and case–based analysis by giving a rough intuitive analysis of the text.

- The fact that the street is a one–way small street suggests that, unless contrary information is available, it can be considered as a single lane, which makes impossible for two average–size cars to share the space. The presence of other cars along the sides strengthens the space limitations.
- Since the writer declares that the other vehicle (say vehicle b) "popped out of ...", he has seen it. Unless they use rear-view mirrors, drivers can perceive objects only in a restricted field. So vehicle b cannot come from behind. It might be ahead or on the right side.
- To avoid a vehicle there are four basic methods: to stop, to slow down, to change lane, to find some free space.

- Stopping is efficient only if the other vehicle does not run into yours. If two vehicles are on the same lane, they must follow (approximately) the same direction for stopping to be of some use.

- The street is one–way. We may assume the vehicle a (that of the writer) and the vehicle b follow the legal regulation. So, stopping is an available strategy.

- To stop before the accident it is necessary to brake during some time, depending upon the velocity of the vehicle, the distance to the other vehicle, etc. The text hints at the impossibility of anticipating the braking, because of the sudden move of the vehicle b and of the presence of other cars, which might have prevented the driver from seeing the vehicle b.

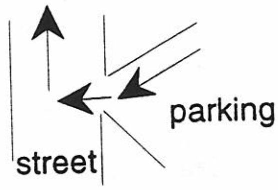
While this information is rather significant, it does not directly provide a technique for detecting causal links. We need to express information at a sufficient level of of detail to capture simple causal connections.

5.1 Types of motions

I distinguish four types of motions:
- pure forward (backward) motions, from back (front) to front (back),
- pure lateral motions from right (left) to left (right),
- mixed motions (e.g. front–left),
- rotations.

Let o be a moving object with an intrinsic orientation, its front being in the direction θ. Let $c(o)$ be the center of o. A left rotation from θ to $\theta + \theta'$, for example, leaves the $c(o)$ unchanged, if there is not other motion, but operates on the position of other points. Rotations are not interesting for motions inside lanes, where the lane behaves as a "carrier" of the vehicle's trajectory. They are important for vehicles which turn or park.
To characterize a rotation the predicate `rot`(VEHICLE,DIRECTION,DIRECTION,ORIENTATION) is used, with the following meaning: during some interval, a vehicle undergoes some rotation from an initial to a terminal direction. The argument of type ORIENTATION indicates the position of the second direction wrt the first. In the text, we understand that Mme Glorieux's car comes from a parking, but we have no information about its initial direction. Suppose that it is like in fig. 2.

Figure 2



If the vertical arrow is the normal direction in the street (recall it is one –way), Mme Glorieux's car needs a serious amount of rotation to normalize its trajectory. This has two consequences; (a) it will take her longer to turn, (b) her vehicle will be more exposed, because (some part of) it will be orthogonal to the street's direction for a while. In somes cases it would be useful to enumerate the main families of position. First we consider to be the relevant variations of the proximity rectangle to be as follows (M and m are the maximum and minimum values).

direction	f0	0l	b0	0r
length	M	m	M	m
width	m	M	m	M

This distribution is relative to a rz of direction f0. What happens when the trajectory is curved? We use the following table:

direction	f0	fl	0l	bl	b0	br	0r	fr

We look for the first direction in the table and run through it rightwards or leftwards, selecting the shortest path until we find the last direction. If the first direction is fr (resp. f0), we may restart from the left at f0 (resp. the right at fr). If there are two possible paths, we keep the twos. For each pair of directions in the transition, the length (resp. width) of the proximity rectangle increases (resp. decreases) or decreases (resp. increases). In the case of Mme Glorieux's car, we get the following sequence: bl $\Rightarrow$ 0l $\Rightarrow$ fl $\Rightarrow$ f0.

This sequence is obtained by resolving the constraint `rot(VEHICLE`,bl,f0, `right)`. The table is scanned leftwards (since it corresponds to a leftward rotation, and we are considering a rightward one). Let L (resp. W) be the length (resp. width) of the car (they are constant). Let Lr and Wr be the corresponding (variable) dimensions of the proximity rectangle. From bl to fo we have the variations:

direction	bl	trans.	0l	trans.	fl	trans.	f0
prox rect.	$Lr < L$ $Wr > W$	$Lr \searrow$ $Wr \nearrow$	$Lr = W$ $Wr = L$	$Lr \nearrow$ $Wr \searrow$	$Lr < L$ $Wr > W$	$Lr \nearrow$ $Wr \searrow$	$Lr = L$ $Wr = W$

Note that all these variations are internal to the proximity rectangle, and are not necessarily significant to a rz as long as we do not know whether (and when) the vehicle is in this rz. In the text, if the position is the one in fig. 2, we can assume that the default direction in the rz which represents the parking is maintained, until the car front touches the front region of the parking rz. To make some interesting conjecture about the subsequent car motion, we need a different notion.
Due to the physical properties of cars (most notably deflection phenomena), it is not possible for a car to rotate by simply moving parts different from its center. When a vehicle rotates from a direction x to some direction y according to an orientation o, its center undergoes a motion of direction 0o which is proportional (other things being equal) to the distance (in terms of transitions) between the two directions. Knowing this is sufficient to deduce immediately that the more the directions are distant the more the car's motion will constitute a potential hindrance.

5.2 Meiri's approach

I use the approach of [5], which integrates qualitative constraints and quantitative constraints. In this approach we have basic object and basic relations. The basic objects are intervals (in Allen's sense) and points, and the basic qualitative relations are Allen's relations augmented with *point-point* (pp) relations, namely $<, =, >$, and *point-interval* (pi) relations, namely $<, starts, during, finishes, >$. pi relations are just as expected: they are really relations between a point and the endpoints of an interval; e.g. for an interval $[I^-, I^+]$ we have the equivalences between $p < [I^-, I^+]$ and $p < I^-$, $during(p, [I^-, I^+])$ and $I^- < p < I^+$, etc.
The quantitative relations involve intervals whose endpoints are numbers which express absolute locations in time. A binary relation $(p_2 - p_1) \in (\alpha, \beta)$ is sufficient here; it expresses the fact that the duration of $[p_1, p_2]$ is at least α and at most β. A constant ∞ is used for open-ended intervals.
The basic tool is a constraint network, whose nodes are intervals or points of time at which (boolean combinations of) propositions hold, and arcs are disjunctive constraints in set form. A qualitative disjunctive constraint between interval nodes $I\{r_1 \dots r_n\}J$ means $r_1(I, J) \vee \dots \vee r_n(I, J)$. A quantitative disjunctive constraint between point nodes $p_1\{(x_1, y_1) \dots (x_n, y_n)\}p_2$ means $(x_1 \leq duration([p_1, p_2]) \leq y_1) \vee \dots \vee (x_n \leq duration([p_1, p_2]) \leq y_n)$.
A person who is in charge of a vehicle can take two different types of action upon it: change its velocity or change its direction. We can express these changes as relevant episodes in a temporal constraint network (tcn). Of course, since we have no quantitative values, our networks are just pseudo-quantitative networks. The advantage in doing so is to make the expression of some dependencies natural. The propositions which hold at some moments

or during intervals are of the following sorts:
- the vehicle velocity remains constant,
- the vehicle velocity increases or decreases,
- the driver notices something,
- the rz curvature is constant,
- the rz curvature increases or decreases,
- the vehicle direction is constant,
- the vehicle direction changes,
- the vehicle position is such and such,
- the vehicle position changes.

Note that the last aspect (position) connects the tcn with the rz description illustrated above.

The *content* of a moment or interval is a finite list of (disjunctions of) propositions, logically interpreted as a conjunction.

5.3 Dependences

We need a notion of *dependence*, familiar in qualitative physics (see [2] for some examples). Well-known dependences hold between:
- the velocity and the direction (when a car runs off its normal path in a curve),
- the curvature and the direction (in the same case),
- the velocity and the time consumed in some motion.

The last dependence holds between a quantitative constraint (an arc of the tcn) and a proposition, while the first two dependences concern propositions (direction) or static features of zones (curvature). The points and intervals in a tcn are not just time landmarks: they store some information about the situation. Static information holds at any point and during any interval: the length or curvature of a rz, the mutual positions of rz's exemplify current static information. Processes, like braking, speeding up, changing one's direction, are stored in some intervals. Average values are stored in intervals, because they depend on the period during which (ideal) measures are made. "Short" events, like noticing something in a rz, happen at time points. The fact that a parameter has some special value, e.g. the two extreme values of the parameter DIRECTION in a rotation, is registered also at time points, and is considered as a kind of short event.

A dependence will be registered as a positive or negative link of general form $dep(pos, x, Y)$ or $dep(neg, x, y)$.

A positive (resp. negative) dependence asserts that some factor (x) tends to increase (resp. decrease) some quantity (y). Suppose that a declaration reports that a car, because of its speed, has run off its path in a curve and bumped into another vehicle coming in front. In this example, the velocity tends to increase the deviation wrt the normal trajectory. To express it I will define a time interval J during which the car follows a path less curved (to left) than the backbone of the rz 1. At the end of J, the car is not inside 1: it can be on the frontier between 1 and 2 or inside 2. That gives a declaration in the following style (in a PROLOG–like notation):

```
time_point(p1).
time_point(p2).
time_interval(J).
vehicle(a).
vehicle(b).
path(path1).
path(path(2).
velocity(v1).
direction(d1).
direction(d2).
place(l1).
line(line1).
frontier(1,2,line1).

during(J,follow_path(a,path2)).
during(J,velocity(a,v1)).
curvature_deg(path2,d1,d2,right,h2).
inf(h2,h1).
starts(p1,J).
finishes(p2,J).
at(p2,loc(a,l1)).
at(p2,or([inside(2,a),on(line1,a)])).
dep(neg,v1,h2).
```

For time–based dependencies, the general rule is:
for any quantity X and any time intervals i, j, if we declare

```
duration(i,alpha).
duration(j,beta).
during(i,X_rate(...,r1)).
during(j,X_rate(...,r2)).
starts_pi(i1,i). starts_pi(j1,j). finishes_pi(i2,i).
finishes_pi(j2,j).
at(i1,X(...,di1)). at(i2,X(...,di2)). at(j1,X(...,dj1)).
at(j2,X(...,dj2)).
eq(di1,dj1).
eq(di2,dj2).
```

then `alpha` > (resp. =,<) `beta` iff `r1` > (resp. =,<) `r2`.

5.4 Motions verbs

The main idea is to divide interrelated motions into different episodes labelled by a small subset of motion verbs. Each of these verbs gives raise to a mini tcn; these tcn's can in their turn be combined to produce complex descriptions. Ideally a user should first define a set of rz's, then create the mini tcn's, by activating appropriate verbs with appropriate arguments, and combining or expansing them.

5.5 The mini tcn's for motion verbs

Here are some mini tcn's under their simplest form. The following typing is shared.

```
direction(1). direction(d2).
time_point(p1). ... time_point(p10).
time_interval(i). ... time_interval(l).
vehicle(a).
object(b).
path(path1). ... path(path2).
rectangle(r).
```

The following specifications are shared too.

```
% variation rate type is raised to degree type
% pr_rec means proximity rectangle
starts_pi(p1,i). finishes_pi(p2,i).
starts_pi(p4,k). finishes_pi(p5,k).
starts_pi(p6,l). finishes_pi(p7,l).
meets_ii(j,k). meets_ii(k,l).
degree(r1). degree(r2).
```

The particular tcn are:
for *accélérer*,

```
duration(i,alpha).
duration(j,beta).
starts_pi(p3,j).
finishes_pi(p4,j).
meets_ii(i,j).
during(i,vel_rate(a,r1)).
during(j,vel_rate(a,r2)).
sup(r2,r1).
```

for *ralentir* just put `inf(r2,r1).`,
for *éviter*,

```
duration(i,alpha).
duration(j,beta).
duration(k,gamma).
starts_pi(p1,j).
finishes_pi(p3,j).
before_pp(p3,p2).
before_pp(p4,p3).
eq_pp(p2,p5).
during(i,follow_path(a_virt,path1)).
during(j,follow_path(a,path1)).
during(k,follow_path(a,path2)).
at(p2,pr_rec(b,r)).
at(p2,hit(a_virt,r)).
at(p5,pr_rec(b,r)).
at(p5,not(hit(a,r))).
```

Here we use a virtual vehicle `a_virt`, showing as a* in the drawings. This is a simple solution to the couterfactuality involved in *éviter*: if `a` had not changed its trajectory it would have hit `b`. Since the other possible changes entailed by the possible change in trajectory, it is sufficient to consider only the possible alternative trajectory. The virtual vehicle For *contourner*, we keep the restrictions of *éviter* and add

```
duration(l,delta).
during(l,follow_path(a,path1)).
```

for *tourner* we have just

```
during(i,rot(a,d1,d2,X)).
% X = right or left
```

for *serrer* (in the process interpretation),

```
segment(side1).
during(i,to(X,of(a),side1)).
during(i,dist_rate(a,side1,r1)).
negative(r1).
%X = right or left
```

for *se déporter*,

```
during(j,follow_path(a,path1)).
during(k,follow_path(a_virt,path1)).
during(k,follow_path(a,path2)).
parallel(path2,path1).
```

Note that *se déporter* does not denote just a change in trajectory, a simpler meaning which could be conveyed by *bifurquer* for instance. The two paths (the real and the possible) must be parallel. Verbs like *bifurquer*, *se déporter*, *obliquer*, when applied to vehicles, presuppose the existence of a path available to the virtual variant of the vehicle. This is not required when *bifurquer* or *obliquer* are predicated of ways (e.g.*la route oblique*). In those cases, the verb can simply describe a change in orientation.

6 Conclusion

Many aspects have been left out in this presentation. I shall mention two of them. First it is necessary to provide some way of linking the descriptions with the relations (meeting, precedence, etc.) on intervals. This is the well–known (hard) problem of extracting time relations from temporal surface forms. It is complicated by the fact that many texts belong to "spoken language", or, more egnerally, denote an insufficient mastering of the time "code". It is not obvious that a temporal interpreter would not be led astray by the texts' syntax. Second, there are many situations which involve planning by the drivers. Although it is possible to express some simple aspects, the construction of a system which would adequately process intentional aspects is far beyond the limits of the present work.

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Connecting Visual and Verbal Space:
Preliminary Considerations Concerning the Concept 'Mental Image'

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Abstract

AI research concerning the connection between seeing and speaking mainly employs what is called reference semantics. Within this framework, the notion of 'mental image' is often used while explaining how somebody not situated in the same perceptual context is able to anchor his understanding of an utterance describing the scene visually perceived by the speaker. We give a foundation for considering mental images as propositions with respect to a certain *field* of concepts: these fields have to provide a *syntactically dense* set of concepts distinguishing locations. The use of such propositions in the reference semantic explanations of understanding utterances about visually perceived scenes is motivated by applying Kant's idea of the introduction of new types of objects: we conceive spatial relations as relations only applicable to *sortal objects*, i.e., individuated objects which are *synthetically introduced* on a syntactically dense field providing their potential locations. The concept 'mental image' which results from these preliminary studies is applied to two current projects in AI, one dealing with the semantics of particular spatial prepositions, and the other more generally concerned with the logic of the connection between visual and verbal space.

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Connecting Visual and Verbal Space

Preliminary Considerations Concerning the Concept 'Mental Image'

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1 Using Mental Images: a Naive Framework

The relation between language and world has attracted the interest of scientists since the beginning of science. Nowadays AI encounters a more restricted version of this question when addressing the problem of the connection between space in its visual and verbal forms. A typical example from our ordinary life is the task of a radio sports reporter: he has to give to his audience a verbal description of spatio-temporal configurations (among other aspects) which he accesses by his visual sense. Usually, the spatial entities to be considered are intuitively classified into those concerning the relations between two or more concrete objects – *spatial relations* –, and those additionally integrating temporal aspects – *spatial events*. The reporter's behavior is often explained by means of the *concept of 'reference semantics'*, i.e., his report is viewed as primarily anchored in his perceptions. The combination of this understanding with the communicational aspect of language leads us to the conception of *mental images*.

Following G.H. Mead, one central aspect of conscious communication is that in the speaking individual, the same reaction is triggered as is in the other individuals (cf. [Mea62, p. 68ff.]): the speaker has to adopt the role of the others in the communicative act. In order to be language, what is said has to be understood by the speaker, as well, and he must be influenced by it in the same way as the others. This is essential since speakers never mention explicitly everything actually communicated: the phenomena of ellipses and anaphora, presuppositions and conversational implicature are just the tips of the iceberg. In AI, partner modeling provides the corresponding explanatory tool. Therefore, we should not examine the reporter without his communicative counterpart, the audience. Radio sports report listeners are involved in cognitive activities approximately converse to the speaker: they have to understand what the reporter has said. However, the conception of reference semantics cannot be simply transferred in order to explain their understanding (and the behavior resulting from it), since the situational setting explicitly excludes any perception of the reported events by the audience: as is indicated by Fig. 1, this problem is usually solved by means of the concept of 'mental images' (cf. [Sch90]). In order to explain how a listener understands the report which is grounded in the visual perception of the speaker, the listener is assumed to construct a *visual mental model* which substitutes percepts of objects not perceptually present: as a German linguist wrote in 1969, *'the radio reporter has solved his task only if he describes the reality of a sports event so vividly and obviously to the listener that the listener believes he sees that reality'* (cf. [Dan69, p. 94]). Following Piaget's detailed classification of mental images, we are concerned with *anticipatory kinetic images*, i.e., images of situations and movements which were not perceived before (cf. [PI66, Chapter 1, § 1]).

In the following, I elaborate this approach to explaining the connection between visual (perceptual) and verbal (communicative) aspects of space by means of the concept of a 'mental image'.

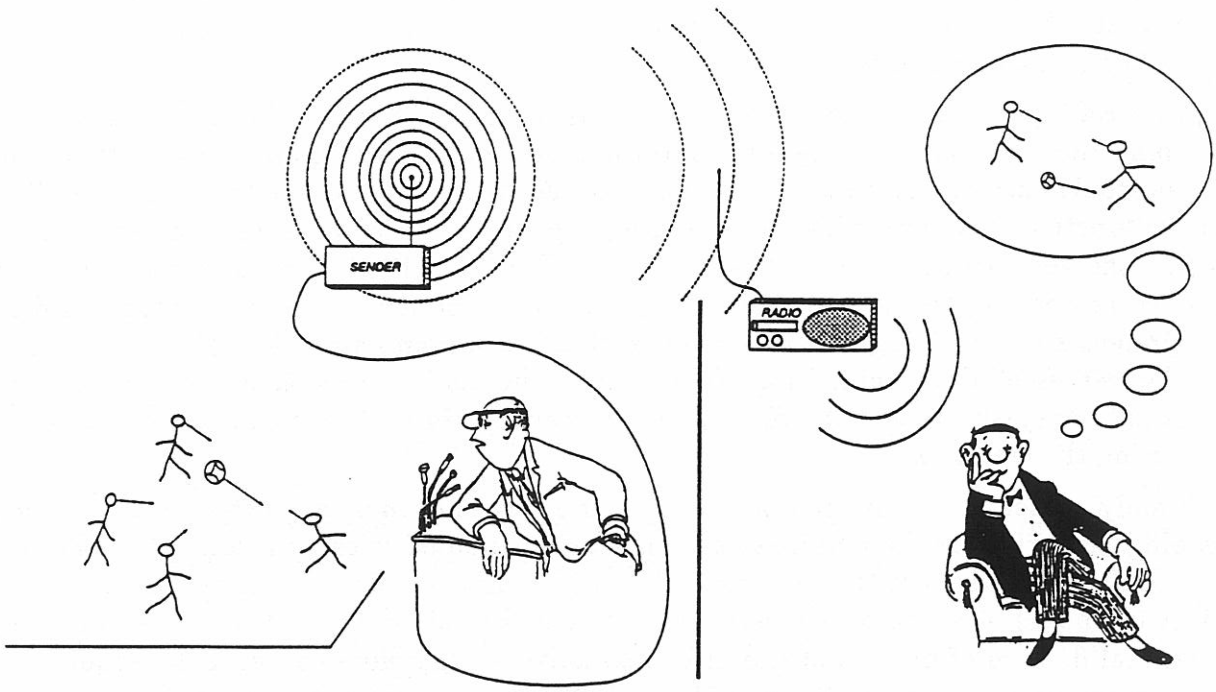

Figure 1: Mental Images as Explanations

2 The Logical Components of an Utterance

We first concentrate on the verbal aspect of space which not only mediates between speaker and hearer, but also is usually viewed to be interpersonally accessible – in contrast to percepts or mental images. While performing his task a radio sports reporter utters primarily singular declarative sentences[1] about concrete things, sentences like (S 1) and (S 2):

S 1 *Miller is not standing in the right half of field.*

S 2 *Miller is doing a double pass with Smith.*

Following the constructivist analysis of logic ([KL73]), singular declarative phrases are logically divided into four parts: one is called the involved set of *nominators* which refer to some given (i.e., already mutually known) individual objects, like 'Miller' or 'the right half of field'. The expression 'nominator' was introduced in [Lor70, p. 214] with the particular aim of obtaining a more distinct separation between logical and linguistical analyses.[2] In comparing the logical and the linguistic terms, the nominators correspond mainly to the noun phrases of the sentence.

The second part is called the *predicator* (cf. [Car47, p. 6]). The function of predicators is to introduce a standard gauge with respect to which the considered objects are rated: a dimension of distinction to be communicated – i.e., proposed to be newly established in the interpersonal discourse universe. In the examples above, we employ the predicators 'to

[1] Here, 'singular' is opposed to 'general': singular sentences concern single objects; general sentences use quantified variables with respect to a domain of objects;

[2] Four types of nominators are distinguished: demonstrator ('this'), indicators ('today', 'you'), proper names ('Miller'), and definite descriptions which use a predicator to specify the object (either in combination with the demonstrator (deictical description; 'this ball') or pure ('the ball')); cf. [KL73, III.8–9];

stand in' and 'to do a double pass with'. In most cases, the predicators are linguistically given mostly by means of the predicates of such a sentence (in a broad sense, sometimes with adjectives and adverbs).

A *logical copula* is the third part of any assertion (cf. [KL73, I.4, and p. 90]): its function is to bind the nominators as arguments of the predicator, and perform the assertion. The logical copulae have to be clearly distinguished from the linguistic copula which essentially has the function of an unspecific verb binding adjectives as predicates to a subject, e.g., in English the verb 'to be' (at least in some uses). Traditionally, two copulae are studied in logic, corresponding to the two sides of a (binary) distinction, and formally expressed by the symbols ε for ascribing the predicator to that set of nominators, and ε' for denying it. Copulae represent the minimal logical residue of the performative aspect of an asserting utterance – they also reflect the corresponding reactions in that language game: accepting or refusing the assertion.

Finally, sentences are uttered in a particular ***situational context*** which determines their meaning: in particular the nominators cannot be understood without a context:[3] following Strawson's explications of the reference relation, a nominator does not simply represent an object by means of a one-to-one relation, but it ***picks out*** an object from a certain given contextual domain of objects of the discourse universe, therefore conceptually requiring a one-to-many relation (cf. [Str71, p. 17ff.] and [Tug76, p. 369ff.]). Since nominators correspond to those objects ***mutually known*** by speaker and hearer, contexts depend crucially on what has been communicated earlier (cf. [Joh76, p. 50f.]). Along this ***horizontal dimension*** of explanation (as I want to call it), contexts are viewed mainly as the comprehension of the text up until that moment (cf. [Kam90]). In the case of the radio sports reporter, the context of his utterances is alternatively conceived as the set of things which he visually perceives. In general, the minimal logical residue of the context of an assertion is represented by the (usually implicit) self-referencing psychological component of that utterance – e.g., 'I see that' + (S 1) – which basically establishes the relation to the speech situation by means of the reference to the speaker ("I") and his understanding of being situated there. Here, the expression ***vertical dimension*** is used to explain contexts by referring to the visual field of the speaker.

In this paper, the representation of an utterance by explicitly and distinctly mentioning its four logical components is called the ***proposition*** corresponding to that utterance. Thus, the proposition – or logical form – of an utterance is a particular kind of abstraction, like 'the verbal manifestation' or 'the syntactical structure' of an utterance (cf. [KL73, III.7]), an abstraction mainly used to explain the understanding of such an utterance. We use the scheme given in formula 1 for propositions: as a variable for copulae, we use the Greek character κ and parentheses around the whole propositional schema; the context is given in the abstract schema by means of the Greek capital letter Δ (reminder for 'domain of objects'). Formula 2 expresses the propositional transcription of assertion (S 1):

$$(\{n_1, n_2, \dots n_i\} \quad \kappa \quad P)_\Delta \tag{1}$$
$$(\{Miller,\ the\ right\ half\ of\ field\} \quad \varepsilon' \quad being\ in\ )_{(Radio reporter\ A,\ Time\ \tau)} \tag{2}$$

[3]Correspondingly, Kamp speaks of ***the need to replace the older absolute notion of propositions by that of a proposition*** relative to ***a context.*** (cf. [Kam86, p. 13f.]);

3 Predicators, Concepts, and Levels of Explanations

Explaining the understanding of an utterance is essentially based on its logical components: the context provides (horizontally or vertically) the multitude of objects among which the nominators identify some. The predicator draws the listener's attention to a distinction applicable to the selected objects, e.g., restricting their attributes or relations. The copula requests him to revise the context appropriately. This revision results in a new context for the subsequent utterance which simultaneously corresponds to the listeners' understanding of the utterance considered. We especially may assume that all implicit information and implicatures drawn by the audience are elaborated in the process of the revision. In general, the subsequent sentence may use the newly established distinctions to specify its objects by means of definite descriptions. The other kinds of nominators are derived from this referring to an already established distinction (cf. [Tug76, p. 326ff.], [Joh76, p. 50f.]).

We want to explain how mental images are (could or should be) used to explain the function of at least one of the logical components of an utterance like (S 1) or (S 2); i.e., we want to explain why a certain kind of explanation of the understanding of such an utterance is adequate. Since the utterances in our focus are characterized by their *spatial* predicators, we concentrate on this component. How can mental images be used to explain the revision process on the context triggered by the spatial predicators?

In order to explain the use of a verbal expression, generally the *meaning* of the expression is mentioned: the meaning of a predicator is called a *concept* – an interpersonally accessible abstract reference point which allows us to rate the validity of the communicated distinction (cf. [Ros90]). Assertions which are used to discuss *about* concepts – i.e., assertions with a nominator referring to a concept and a predicator highlighting or introducing attributes of that concept – are called *methodological* with respect to that concept. Sentences with a predicator corresponding to that concept are called *empirical* (with respect to the concept). An important use of methodological sentences with respect to spatial concepts is called *Spatial Reasoning* (or *Spatio-temporal Reasoning*, respectively).[4] The empirical sentences with respect to spatial concepts – like (S 1) and (S 2) – form the *Object Level*. The corresponding methodological sentences declare distinctions of the abstract reference points of the Object Level, i.e., relations and attributes of spatial concepts. The set of concepts specified here outlines the verbal aspect of space: therefore, this level of sentences is called the *Spatial Level*. Rather obviously, such conclusions drawn by Spatial Reasoning have to be founded, as well: i.e., we have to consider methodological sentences of a higher level: methodological sentences with respect to predications of concepts. This is called the *Methodological Level* (methodological in the closer sense, namely independent of a specific concept). The core of this level is clearly the concept of 'concept' as such: we can use the properties which we commonly ascribe to a concept by virtue of being a concept for founding the explanatory power of methodological sentences about that concept, e.g., sentences on the Spatial Level used in Spatial Reasoning. Our question as to the explanatory power of mental images belongs to this level: we are interested in the relation between the concept 'mental image' and the concept 'concept'.

[4] We here use this expression for syllogism-like combinations of a methodological sentence about spatial concepts with corresponding empirical sentences, e.g., the following rather simple conclusion:

$$\frac{(\{\textit{the church, the book shop}\}\ \varepsilon\ \textit{Being Left}),\quad (\{\textit{Being Left, Being Right}\}\ \varepsilon\ \textit{Being Converse})}{(\{\textit{the book shop, the church}\}\ \varepsilon\ \textit{Being Right})}$$

Due to the restriction on the length of this paper, we cannot go into the illuminating historical development of the contemporary concept of 'concept' from the ancient understanding as an eternal Form, through the scholastic conception of the three types of universals – before, in, and after the particulars – and the explanation of concepts as an autonomously created private mental entity to be found in the Philosophy of Enlightenment, although we conceive them as highly relevant for our theme. A corresponding discussion with respect to Spatial Reasoning is given in greater detail in [Sch93, Sect. 4], a general investigation is to be found in [Ros90]. In the following, we solely pick out essential components of Kant's conception seen from a more modern non-mentalistic perspective.

4 Concepts and Mental Images

The relation between the concepts 'concept' and 'mental image' originates essentially from the mentalistic framework of the Philosophy of Enlightenment: *'the word 'concept' (or other words used as equivalent) was conceived as referring to a mental phenomenon which is generated autonomously by the human mind, directly accessible in the 'inner world' (or consciousness) of the human being, and which should enable the human beings who have it to prove the validity of predicative statements'* (cf. [Ros90, Vol. II, p. 11]). In the dawn of this position, Descartes and especially Locke understood a concept to be a mental image, or more precisely, a *prolongated perception* of a corresponding particular which serves as a *prototype* for similar particulars. However, this interpretation ran quickly into severe problems (cf. [Ros90, Vol. II, p. 55ff.]). Integrating parts of this idea with Leibniz's conception of a concept to be a human faculty, i.e., a *mental program* for recognizing corresponding instances, Kant in the heydays of the Philosophy of Enlightenment presented an elaborated theory of a two-fold mental construction: first, he considers a human faculty of constructing concepts which, second, themselves are mental faculties to construct *intuitions*, i.e., mental representatives of instances, or more colloquially: mental images (cf. [Kan65, B741f./A713f., A105, and B180/A141]).

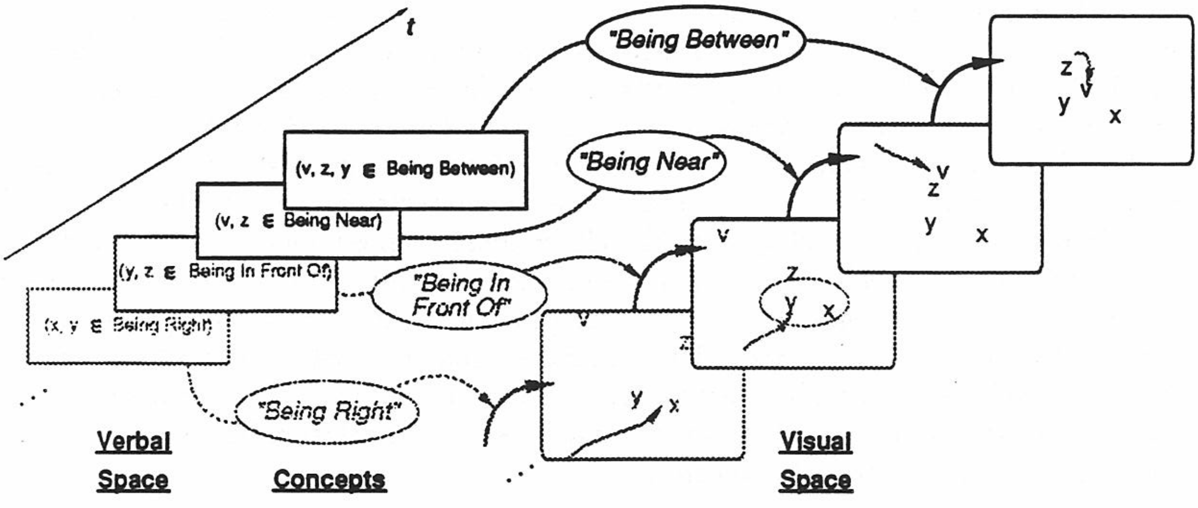

Figure 2: Concepts Mediating Between Verbal and Visual Space

Kant's second step, the construction of mental images of instances, was resuscitated in contemporary Cognitive Science by Johnson-Laird under the name of *mental models* (cf. [JL83]). Fig. 2 illustrates the connection to the explanation given above: in the mentalistic tradition, the context of an utterance from which we start is interpreted as a mental image (or model); the nominators of the utterance under investigation are expected to refer to elements of that image; its predicator is used to communicate a distinction with respect to a concept – that is here, a certain mental faculty. By means of this faculty, the contextual mental image is transformed into (the image of) a concrete instance of the concept. Therefore, all implicatures of the application of the corresponding distinction in the given context have to be present in the resulting model. But they are not yet explicitly accessible. This can only be achieved by means of the concepts corresponding to those implied distinctions: they have to be applied to the mental image in order to recognize explicitly the implicatures, and thereby also transform the image into the representative of the context of the following sentence (cf. [Pri91]; the recognition of the implicatures is not shown in Fig. 2).

Though, in order to avoid the solipsistic consequences of conceiving concepts as private (i.e, explicitly *not* interpersonally accessible) mental entities, we should follow Wittgenstein (cf. [Wit53, §§ 656 and 25] and [Ros90, Vol. III, p. 35ff.]): the mentalistic terminology of the Philosophy of Enlightenment has to undergo a *linguistic turn*: mental phenomena have to be reinterpreted as a particular form of methodological communicative behavior used to explain other verbal behavior. *'We describe the technique of using words by means of words'* (cf. [Wit89, p. 128]). Concepts should be understood as abstractions of verbal behavior which are used to interpret, explain, and interpersonally coordinate this kind of behavior. Instead of being mental entities existing before the corresponding verbal behavior, they are derived from it, and therefore secondary to it.

The important question remains: where do these faculties to construct or revise mental models come from, and what do they look like. Kant's answer is, as was mentioned above: they also are autonomously created – or synthesized – by the human mind.

5 The Making of a Distinct Concept

By 'synthetically creating a concept', Kant does not mean the definition of a concept on a given set of elementary concepts which all distinguish properties of a given type of object, i.e., concepts within one *field*.[5] In this case, the composed concept is already completely *preformed* in the set of elementary concepts: it is merely a symbolic abbreviation for a particular combination of the elementary distinctions, since in fact no new kind of distinction is introduced. Kant had in mind a totally different kind of introducing concepts, which really *extends* the capacity to recognize: the *'making of a distinct concept'* instead of merely *'making a concept distinct'* (cf. [Kan60, Introduction, § VIII]). He wants to *synthesize* a completely new field of concepts, i.e., concepts distinguishing the attributes of a completely new kind of objects, by combining several given but unconnected fields of concepts. Like the construction of mental models, this construction has to be adjusted to a reference point, as well: in constructing a field of concepts, we use, so to speak, a description of our goal – a 'blueprint' – which specifies the internal relations between the concepts of that field, and thus, restricts its possible realizations by means of a synthesis of other fields of concepts which are already given (in Kant's terminology: 'real'; cf. [ibidem]). For example, the introduction of the rational numbers as a combination of two (sets of) integers (counter and denominator) or of the complex numbers as a pair of real numbers should be viewed as a synthesis in the sense of Kant. All fields of concepts have an internal structure: we with Kant are now mainly interested in the external relations between the

[5] A field of concepts – also called an incompatibility domain – puts together concepts which are applicable to one type of objects but cannot be applied simultaneously to a particular object of that type; colors form such an incompatibility domain: a one-colored object cannot be simultaneously red and green; in fields of graded concepts, like the spatial field, usually also the incompatibility is a matter of degree;

internal structures of several fields. Kant calls the specification of the relations between the concepts within one field its *logical rules*, e.g., in the form of an axiomatic system generating that field. The set of rules connecting several fields to create a new field is called the *(transcendental) schema* of the new field (cf. [Kan65, B174/A135]).

Feeling obliged to make the linguistic turn, we shift the focus of our attention from the construction of a concept understood as a private mental entity to the corresponding explanations we could give for the explanative power of a concept conceived as an abstraction of verbal behavior: in order to explain why the concepts of a certain field (e.g., the field of spatial concepts) can be used to explain the utterances of the Object Level (e.g., by means of Spatial Reasoning) we could remain within that field of concepts, employing merely the internal definitions and logical rules of that field: because the concepts of 'being right' and 'being left' are converse, we can conclude that, if an object is to the left of another object, the latter is to the right of the former. In this case, the conversity of the two concepts cannot be explained, as well. However, applying Kant's understanding, we additionally could consider the schema of that field which then is viewed as receiving its internal structure from other fields of concepts: the logical rules of the former can be reduced to the logical rules of the latter. With respect to the example above, this allows us to even give an explanation for the conversity of 'being left' and 'being right': it has to be a consequence of the particular combination of the concepts of the simpler fields with their characteristic logical structures. Correspondingly, *judgments a priori*, which in Kant's terminology correspond approximately to propositions of methodological utterances – e.g., 'The concept of 'being in' is transitive in the following cases ...' – are distinguished with respect to the involved kind of foundation in analytic and synthetic judgments. *Analytic judgments a priori* are founded by means of the logical rules within one field of concepts – its *internal* structure. *Synthetic judgments a priori* integrate additionally the schema connecting several such fields in their explanation, i.e.: synthetic judgments a priori are propositions which have to be founded by explaining the logical rules of a concept of one field *externally* by the logical rules of the concepts of other primarily independent fields by means of the schema.[6] With a synthetic judgments a priori, like 'This concept has those properties', a certain *genetic* aspect is contributed to argumentations about the attributes of a concept: the claim is laid for a foundation by means of a sentence like '*because we conceive this concept in its field as constructed in such a way (schema!) from concepts with such attributes (logical rules).*'

There exists a close parallel between the distinction between logical rules and schemata of a field of concepts on the one side, and the distinction between *specification* and *implementation* of an Abstract Data Type (ADT) on the other side: the specification of an ADT, e.g., by means of a set of algebraic equations (cf. [EM85]), declares axiomatically the attributes of and relations between data types internal to an ADT. The implementation furthermore reduces an ADT to one or more others: data types of the implemented ADT are projected to data types of the implementing ADTs: this is the 'schema' of the implementation, so to speak. By means of this schema, the specification of the implemented ADT can be *founded* on the specifications of the implementing ADTs: the equivalent of a methodological sentence in the theory of ADTs, like, for example, 'Multiplication of any rational with the rational multiplicational identity unit results in the same rational' can be understood both analytically – because it follows from the specification of that ADT *Rationals* – or synthetically – because it is a direct consequence of the particular combination of two (sets of) elements of the ADT *Integers* to one element of *Rationals* and the definition of the rational multiplication on such tuples by means of the operations of *Integers*.

[6]This is a rather simplified presentation of Kant's concept of 'synthetic judgments a priori'; for a detailed description: cf. [Ros91], and even more elaborated in [Ros90, Vol. II, Chapter 3];

6 The Horizontal Dimension of Explanation

We now can interpret the sentences of the Spatial Level (i.e, the methodological sentences with respect to spatial concepts, like the rules of transitivity of the concept 'being in' or the rules of conversity between the concepts of the projective prepositions) as analytic judgments expressing the internal structure of that field. We also may use this level primarily to logically explain the adaptation of the context resulting from a new utterance: to that purpose, we describe the context – i.e., what we assume to be the common knowledge of speaker and hearer – by a set of sentences empirical with respect to spatial concepts.[7] Methodological sentences (among the logical rules of the Spatial Level) corresponding to the predicator of the new utterance are selected and used to add further statements to the context in the syllogism-like manner of Spatial Reasoning, thus making explicit the implicatures of the utterance in that context. This kind of explanation is often called misleadingly 'propositional' in Cognitive Science (cf. [Pri91, (e.g. Sect. 2.2.1)]). We call it the *horizontal dimension of explanation*, since the context is based totally on the analysis of what was said before, and its revision takes place within merely one field of concepts. Note that, for example, the 'empirical' rules of transitivity for the use of the concept 'being in' given by Vieu (for the contemporary French; cf. [Vie91, p. 225ff.]) can be used exactly in this manner without considering any other field of concepts: the objects of the spatial field have different possible attributes which govern the transitivity of 'being in'.

7 The Vertical Dimension of Explanation

We also may interpret the sentences of the Spatial Level as synthetic judgments: for example, we may say that the concept 'being in' is in certain cases transitive and in other not, *because* it is introduced – or implemented, if we use the terminology of ADTs – in a particular way on concepts of other fields with their characteristic internal structures or specifications. [Vie91] again provides a very good example to demonstrate this kind of explanation, and simultaneously to focus on the two fields of concepts which we conceive as crucial for implementing the Spatial Level, as well: the field of configurational Gestalt concepts (geometrical level), and the field of functional part-whole concepts (functional level). As was said above, all concepts of a field fit to a certain kind of object the attributes of which they distinguish: this kind of object constitutes the whole field. Therefore, the synthetic combination of several fields to a new field corresponds to the establishing of a new type of object combining or merging attributes of the objects underlying the implementing fields of concepts. Following Vieu, spatial concepts like 'being in' only can distinguish relations between objects which have both perceptible configurations and non-perceptible functions. The rules of transitivity mentioned above are used as the core of the 'blue-print' for implementing the spatial field.

Vieu's field of geometrical concepts distinguishes objects called 'individuals' (adopted from Clarke's calculus of individuals) by means of their configurations. Although logically including Euclidean geometry, this field is too weak for the specification of the spatial field; e.g., it is not rich enough to show analytically the particularly restricted transitivity of 'being in'. In contrast to the classical Euclidean geometry based on the primitive object 'point', in Vieu's specification of the geometrical level, points of time and space are derived from

[7] In fact, a context should be conceived as one compound proposition, logically composed from a set of elementary propositions; we ignore here the characteristics of the logical junctors involved, since they do not contribute any important features to the present discussion;

the basic concept 'individual' which approximately corresponds to the concept 'Gestalt' in Gestalt psychology – an undivided whole distinguished as figure from the ground.

Vieu's field of functional relations spans around the concept of an object which consists of functional parts or is a functional part of other objects. The relation between a ring of gold and the substance of gold used in the ring, the relation between a forest and its trees, the relation between a car and its constructive parts all exemplify different versions of the functional part-whole relations considered on this level. Note that such a particular whole may stay the same although some of its parts may change.

The spatial field centers around the concept of an object which both has configurational properties and is involved in functional part-whole relations: every object of the spatial field can be projected onto an object of the functional field and an individual of the geometrical field (cf. [Sch93, Sect. 4.2.3.h]). This also means that all the parts such an object has due to the relations of its projection to the functional level also have a configurational counterpart on the geometrical level. In fact, by means of the synthesis of these two fields of concepts, Vieu introduces as the backbone of the spatial field a concept of 'object' equivalent to Strawson's concept of *'sortal universals'*, i.e., that kind of object we usually have in mind when we use the expression 'concrete object' in the close sense: perceptible, countable, persistent over time even if not perceived (cf. [Str71], [Tug76, p. 453], [Sch93, Sect. 4.3]). Sortal concepts like 'chair', 'car', or 'human being' are distinguished from concepts like 'fog', 'red', 'fast', 'water', 'gold'. As a characteristic, sortal concepts contain a criterion to identify and distinguish different individual objects of the same sort, and thus firstly enable us to point to one such individual *as an individual*, or to count several of them: sortal concepts *individuate* their instances. Similarly to two red objects which are not distinguishable already by their being red alone, the functional parts of a car, for example, do not already distinguish one car clearly from another one, since they both have – within a certain range – the same functional structure, and are therefore functionally undistinguishable. Only the different geometrical components of two instances of 'car', or with Vieu's words: their different *histories*, allow us to distinguish both, e.g., by means of pointing. On the other hand, it is not the mere configuration which makes something a car, but the functional relations between the configurational parts.

Founding the properties of spatial concepts synthetically thus means to explain them by means of the interaction of the properties of the geometrical and the functional field. We call this aspect of explanation the *vertical* dimension, since the synthesis *constructs higher*, i.e., more complicated fields of concepts, from simpler ones. Any set of propositions – or context – on the spatial field of concepts can be vertically explained as a synthesis of a set of propositions on the geometrical field with a set of propositions on the functional field: each spatial proposition predicating on a sortal object is projected to configurational propositions predicating on the – perceptible – histories of the sortal objects, and functional propositions predicating on its mereological relatives.

The geometrical level provides those concepts used to describe the (essentially visually) perceptible attributes of sortal objects, aspects which are assumed to be already commonly given, that is interpersonally established. Common between whom? Remember that we here are involved in the endeavor to determine the concept of 'perception' and 'communication' used by somebody who explains somebody else what the exemplary radio reporter is doing: this person while founding synthetically the concepts of the spatial field which he ascribes to the radio reporter uses the geometrical level as a field of concepts he and his vis-à-vis already agree upon. In this case, the interpretation of a context of the geometrical field as a corresponding context of the spatial field (with an appropriate functional presupposition) can be viewed as an explanation of perception: the geometrical field provides in this case the visual aspects of space. Moreover: since the projection of a spatial context onto the geometrical level results in a set of propositions concerning the configurational relations between individuals, we should look for arguments to take this projection to be an *image*.

8 Images and the Syntax of the Pictorial

Why are we inclined to call contexts of the geometrical field images, but not the contexts on the functional or spatial fields? The relevant criterion presented by N. Goodman ([Goo68]) restricts the set of concepts in a field, i.e., the set of predicators used there, and the relations between them. In other words, the structures of contexts possible on that field, that is, the *syntax* governing corresponding propositions (in a very general sense of syntax; cf. [Sch91, p. 88]) gives us the clue for the pictorial: contexts of such fields with a characteristic syntax are images.

Goodman suggests to conceive *syntactical density* of the system of predicators expressing the geometrical field as an essential and for our purpose (though not generally) sufficient criterion for pictorial systems (cf. [Goo68, p. 226]). A system of predicators is called syntactically dense *'if it provides for infinitely many characters* [i.e., predicators] *so ordered that between each two is a third'* (cf. [Goo68, p. 136]). Scholz ([Sch91, p. 97]) remarks that this does not mean that any single context of such a field contains an unbound number of propositions with infinitely many predicators; it only is necessary that – on the Methodological Level – the field as such provides the potential of an unrestricted number of densely ordered concepts some of which are used in a particular context. With that, two individual contexts may be similar to any degree without being identical. This is true for ordinary pictures since for example any spot of color in a picture may be moved a very small distance to get another similar image: no matter how small the distance is, we always can think of a picture with that dot shifted only half the distance. In consequence, the proper application of such a predicator is not strictly decidable in the computational sense: after a finite time, the 'conceptual neighborhood' of concurrent predicators is reduced but not eliminated.

Vieu's geometrical level logically includes Euclidean Geometry: that is, its specification permits to define the concept of a zero-dimensional point with the corresponding attribute: location. Since the Euclidean concept of a location corresponds in fact to the concepts of the densely ordered real numbers, they form a syntactically dense field of concepts: for example, for any pair of predicators 'having location x' and 'having location y' (with the 'internal' real numbers x and y), the predicator 'having location $\frac{(x+y)}{2}$' is also in the field and, in the above sense, *between* the former two.[8] In contrast to that, the set of predicators expressing the functional field is not densely ordered: the mereological predicators can be clearly distinguished, as is the case for the set of predicators of the spatial field: the concepts 'being left' and 'being near' may be applicable to the same particular case, but in the description of such a case on the spatial field, we clearly can distinguish the propositions $(\{X, Y\} \, \varepsilon \, Being\,Left)$ and $(\{X, Y\} \, \varepsilon \, Being\,Near)$ within finite time.

Last but not least, we call these pictorial contexts on the geometrical level *mental* because we use them in explanations of conscious behavior. This conception of the mental is not private, as was the understanding in the framework of the Philosophy of Enlightment,

[8] In any particular context of the geometrical level of Vieu, only a finite number of points is realized – the construction of points in Clarke's calculus of individuals results only in the *relevant* points for that context (cf. [Vie91, p. 130f.]); but infinitely many contexts can be constructed which are similar to any degree to that context; cf. also [McG84, p. 213ff.: ('Gesamtheit und System')];

but (like the whole explanation) interpersonally accessible. 'Mental image' in this understanding is not defined in opposition to 'proposition', since a mental image is conceived as a set of propositions of a certain field of concepts with a characteristic attribute – syntactical density.[9]

9 The Connection between Visual and Verbal Space

Let us finally consider the interaction between the horizontal and vertical dimensions of explanation of the understanding of an utterance in its context: if we integrate a reference to the schema of the spatial field to the horizontal ('propositional') explanation given above, i.e., if we change from analytic to synthetic judgments, the revision of the context by means of the predicator's concept is now explained in three steps (cf. Fig. 3):

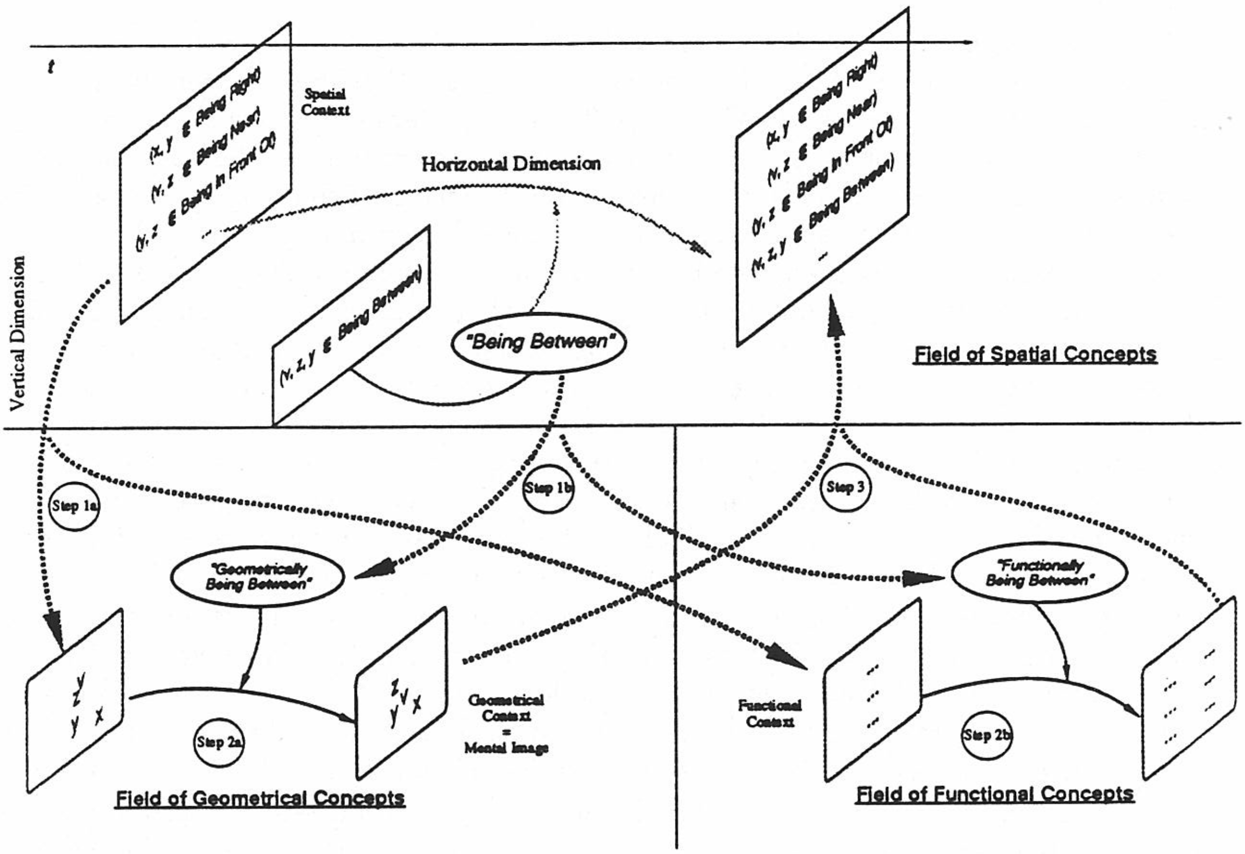

Figure 3: Interaction of Vertical and Horizontal Explanations

- First, the proposition of the utterance is transformed into a corresponding structure of sets of propositions on the lower fields following the schema of the spatial field (1b). According to our definition above, in the geometrical field, the context of the utterance corresponds to a mental image (1a): we here meet again the perceptual aspects of Kant's conception of intuitions and Johnson-Laird's understanding of (visual) mental models which both represent the context in their explanative systems.

[9]Note that this criterion clearly excludes approaches to mental images based on discrete cell matrices;

- Second, the revision of the context by means of the spatial concept communicated by the predicator of the utterance takes place on the lower fields (2a & b): the corresponding projections of the context are revised by those concepts of the lower fields implementing the spatial concept thereby taking into account the interactions between the implementing fields given by the schema. The horizontal dimension of explanation is shifted down one level, so to speak.
- Third, the resulting mental models on the lower fields – especially the mental image of the geometrical level – are synthesized back to the spatial field where they form the wanted mental model used as the context for the subsequent utterance (3): this corresponds to the already mentioned application of the spatial concepts to make explicit the implicatures in the revised model.

The analytic explanation of the transformation of a context by a new predication is explained by a set of associated transformations in the implementing fields of concepts and the corresponding shifts between the implemented and the implementing fields. Thus, the concept 'mental image' as we understand it here comes into the explanative game if the field of concepts we are investigating is viewed as synthesized using a syntactically dense field of concepts – like the geometrical level of Vieu.

A corresponding integration of the vertical and horizontal dimensions of explaining spatial cognition is exemplified by the system SOCCER of the project VITRA: in this case, the exemplary radio sports reporter from the beginning is considered (cf. Fig. 1). The explanation of the visual perception, which is part of the foundation by reference semantics of the utterances of the radio reporter, starts from the field of spatial concepts and views it as implemented on a cascade of lower fields of concepts down to a special field conceived as the common basis to describe the visual field of the reporter in VITRA: the field of the 'digitized image sequences' describing the output of a video camera. This rather poor field contains the concept of a very special and unusual kind of object: an instantaneous dot with a location (relative to the camera-system) and an intensity (grey-value) – the only elementary attributes of the objects on this level. The field of spatial concepts in SOCCER (cf. [Sch90], [Her92]) is based on elementary concepts like distance and direction which allow us to define simplified versions of the well-known static spatial relations, like 'being in', '- at', '- near', '- to the left', etc. These concepts rely on a reduced version of sortal objects: rigid objects persistent over time, with form, location, and velocity. The concept 'distance' is also used here in the temporal sense – as duration of the phases of events: in combination with the spatial relations, it is involved in defining the concepts of spatial events, like 'doing a double pass with'. These relations are internal to the spatial field and form the logical rules of that field in SOCCER. They are synthetically based on the syntactically dense field of concepts of the digitized image sequences. The system XTRACK (cf. [Kol92]) describes the mapping from the simplified version of sortal concepts used on the spatial field in VITRA to the field of 'object candidates' – corresponding approximately to Vieu's 'histories' – and a field of simple part-of relations.[10] These object candidates are projected down to 'digitized image sequences' by the system ACTIONS (cf. [Sun88], [SBSZ87], and [HSE+89]) which encorporates as schema Gestalt principles, like grouping of similar elements and good continuation. With these two schemata, the concept of 'perception' in this explanatory framework founds the reporters spatial utterance in the description of his situational context on the level of the 'digitized image sequence': starting from the digitized image sequence as the primary description of the visual field commonly ascribed to the radio reporter, maximally coherent interpretations are constructed successively on the higher

[10] At present, XTRACK is not yet integrated in SOCCER;

fields. Finally, some propositions of the spatial field are chosen to be communicated and transformed into a corresponding verbal manifestation – following the concept of 'reference semantics'.[11]

As was mentioned above, Mead expects that any adequate theory of communication explaining the behavior of a speaker also has to consider the audience in a particular way: the speaker has to be conceived as somebody who sets himself in the position of his audience – playing anticipatorily its role in the language game – in order to consciously communicate. In VITRA, this demand is redeemed by means of the listener model ANTLIMA (cf. [Sch90]): we focus here only on the static spatial relations, as in sentence (S 1), although spatial events as in (S 2) are dealt with, as well. The understanding of the audience is modeled with the three steps described above: first, the proposition of the (planned) utterance is projected to the lower levels synthesizing the spatial field: i.e., from restrictions of the spatial interaction with other objects to restrictions of the locations of the objects (corresponding to the result of XTRACK); this transformation – the schema of the corresponding spatial concept – is encoded in ANTLIMA by means of functions called 'TyPoFs' (cf. below and Fig. 4); second, the context of the planned utterance is revised on the lower level, i.e., as mental image, following the schema: the locations of the objects are chosen by means of a hill climbing algorithm ruled by the TyPoFs and depending on the contextual positions (cf. Fig. 4 illustrating the influence of three different geometrical contexts (starting positions) on the selected location); third, the schemata of the spatial concepts are applied to construct the context on the spatial field with the explicit implicatures. Finally in the listener model, the resulting context modeling the anticipated understanding of the audience has to be compared with the intended understanding, i.e., what has been perceived: the differing propositions are used in an *anticipation feedback loop* to found the selections of propositions and their verbalizations uttered.

In this case, using a syntactically dense field of concepts to explain a syntactically sparse field results in two interdependent characteristics. First, the concepts of spatial relations are *graded*, i.e., although an unbound number of locational propositions is associated with one spatial proposition, they are not all associated in the same strength: some locations are more typical with respect to a spatial relation than others, or viewed from the other direction: the spatial description is better applicable to some locational descriptions than to others. The functions which encode in ANTLIMA this mapping are therefore called *Ty*picality *Po*tential *F*ields: for the concerned spatial proposition, they associate to every corresponding proposition on the geometrical field a typicality value – a real number $\in [0 .. 1]$ graphically represented in Fig. 4 by means of grey values. The gradation allows us to formulate an important selection criterion which directs the communication between the speaker and his audience: both expect that the *most typical interpretation* of an utterance is intended, and that discrepancies must be mentioned explicitly. Second, the syntactical density of the geometrical field restricts the possibilities to find the resulting contexts in a characteristic manner: as was said before, the predicators in syntactically dense fields cannot be distinguished by means of a decidable algorithm. Correspondingly in ANTLIMA, we are not able to select the undoubtly optimal positions. But a procedure of stepwise approximation on the basis of the gradedness of the spatial concepts – hill climbing – enables us to find at least an 'almost best' location.

[11]The field of spatial concepts is used also as a basis to implement even higher fields of concepts, especially those around the concept of an object involved in intentional activities and autonomous self-control – like the players of a soccer game – and teams of such objects (cf. [RS91]);

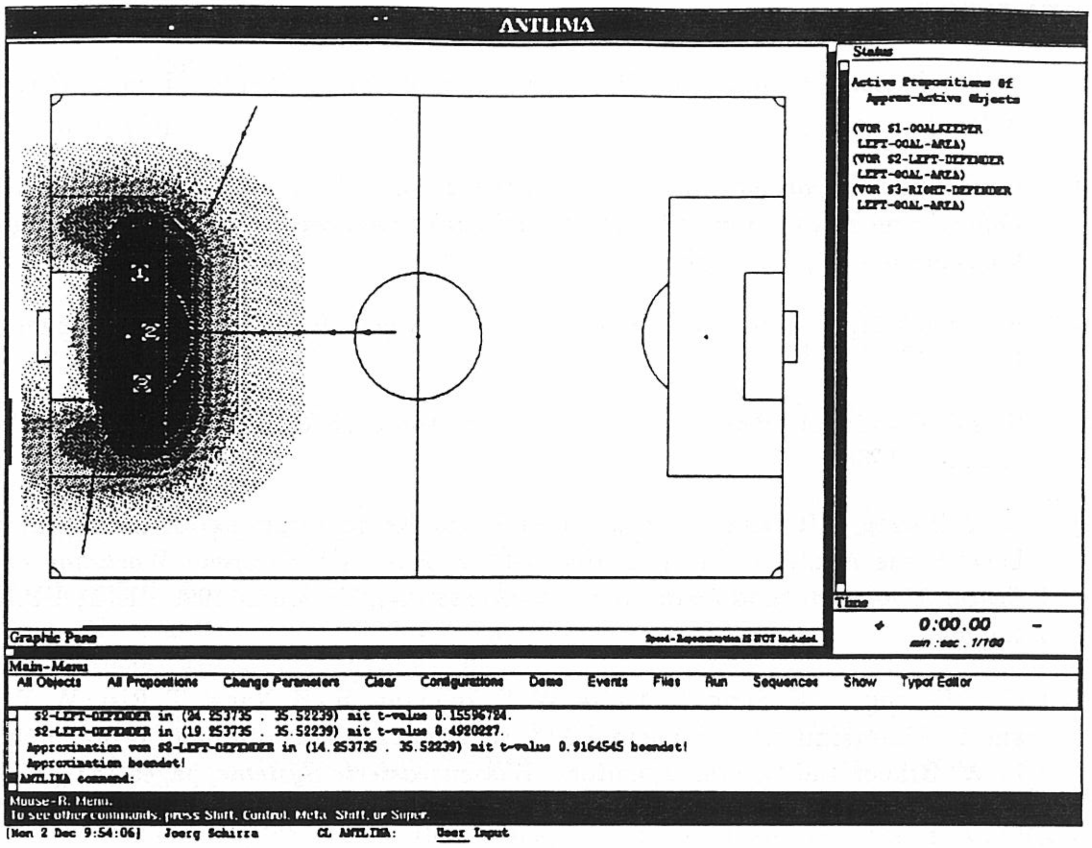

Figure 4: Typicality distribution of the spatial relation 'player in front of the penalty area'

10 Conclusion

On the preceding pages, we presented in a preliminary manner how the concept of 'mental image' can be introduced and applied as a meta-explanative tool in reference semantics: on the basis of Kant's distinction between analytic and synthetic methodological propositions and Goodman's concept of 'syntactical density', we determined the concept of 'mental image' to distinguish the contexts of a syntactically dense field of concepts used to synthetically found the field of spatial concepts. The validity of this conception was motivated by applying it successfully to two – on first view rather different – approaches in AI: Vieu's logical analysis of the predicator 'being in', and the project VITRA concerned with the connection between vision and language systems. Mental images play a crucial role if we integrate the concept of 'reference semantics' anchoring utterances in the situational (here visual) context with Mead's conception of conscious communication: if communication depends on the speaker's anticipation of the audience's comprehension, the reference semantical connection between visual and verbal space demands for the reconstruction of perceptually absent referents in the form of mental images: ANTLIMA, the listener model in VITRA, exemplifies this idea.

M. Beckenkamp, K. Buchholz, E. Hays, W. Maas, P. Olivier, S. Pribbenow, A. Ros, P. Sablayrolles, D. Schmauks, and L. Vieu have to be heartily thanked for their comments and discussions on the theme of this paper.

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Parts of two drawings from *Loriot's Heile Welt* (Diogenes, Zürich, 1973) were used for Fig. 1;

II

SEMANTICS OF TIME :

FROM LEXICON TO DISCOURSE

Preanalysis of French adverbials of date

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Abstract

The work and the parser presented in this paper deal with the preanalysis of texts in natural language.

The first section (§1-2) contains both a theoretical description of Kleen grammars and finite state automata on wich the work is based as well as an explanation of the need to develop new tools for handling larger quantities of data which can be transfered, customized and corrected more easily. It is a problem that involves arranging data in lexical classes which are accompanied by acceptability values.

The second section of this paper (§3-4) contains an expose of a program written to recognise French adverbials of date.

Résumé

Les travaux et l'analyseur présentés dans cet article illustrent la notion et l'intérêt d'une préanalyse d'un texte en langue naturelle.

Une première partie (§1-2) expose d'une part la base théorique de ces travaux qui est constituée par les *grammaires de Kleene* et la *théorie des automates à états finis* et d'autre part la nécessité de développer des outils de représentation nouveaux, afin de gérer un grand nombre d'informations et de permettre une description plus lisible (et donc adaptable, corrigible, portable, ...) de séquences relativement complexes. Il s'agit de la représentation sous forme de *classes lexicales* accompagnées de *tables d'acceptabilité*.

Une deuxième partie (§3-4) est constituée par la présentation d'un programme de *reconnaissance automatique des adverbes de date du français* réalisé dans ce cadre.

0. Intrduction

The work and the parser presented in this paper are based on the theories of *Kleene Grammars* (*cf.* Kleene S.C. 1956), who are known as regular grammars according to the classification of Chomsky N. and Miller G.A. (1963). These grammars, that can be implemented as finite state automata are not suited for natural language parsing in its entirety as pointed out by Chomsky N. amongs others (1957). This syntacticanalysis of natural language has thus become the topic of many more complex theories, like *Harris String Grammars* (1962) for example, *Unification based Grammars* (*cf.* Shieber S. 1986) or even *Applicative Grammar* (*cf.* Desclés J.P. 1990), *etc.*

However, if we are really working on natural language, using real size dictionnaries, the simple search for lexical segments leads to multiple interpretation for each word and often overloads

* The author thanks Robert Sexstone for the translation of this manuscript.

the analyser with unnecessary work. For example, the single word *la* should systematically be linked with three interpretations: a feminine article or pronoun, but also a masculine noun.(the note A). This is where Kleene Grammars are useful, to preanalyse texts at the lexical level.

The object of this paper is not therefore the Syntactic Analysis of natural language, but its preanalysis, designed to precede some sort of syntactic analyser. This work was also the subject of a PhD thesis at LADL[1],where a lot more research was carried out in the domain of lexical analysis.

The LADL dictionary, the DELAS, includes more than 80000 single words (non flected forms) and which becomes a dictionary of more than 550000 inflected terms (*cf.* Courtois B. 1989). After consultation of this dictionary, a method for preanalysis has been implemented in order to lift out as many ambiguities as possible using Kleen Grammars, which has been called *local grammars*. Other work of this nature involving local grammars on clitics and on the contraints which influence the appearence of apostrophes and hyphens (*cf.* Silberztein M. 1989).

But, if single words create ambiguity due to multiple interpretation, it is still not comparable to the problems raised by the enormous amount of compound words or fixed expressions that occur in natural language texts like newspaper articles. Semantic non compositionality, the impossibility of certain derivations, multiple combinations and intepretations cause a parser to perform many useless analyses. For example, you can *have a ball* litterally and figuratively!

The use of *local grammars* allows us to de-ambiguise a lot of a text. To do this a dictionary of more than 90000 non inflected compound terms which becomes a dictionnary of 140000 inflected terms join the DELAS dictionary, this one as been transformed into a system of *local grammars* (*cf.* Courtois B.and Silberztein M. 1990).

My aim was to prove that it is possible to go further still with this text preanalysis in order to develop the tools necessary for handling large amounts of information and still using *Kleene grammars* as a tool.I have chosen to study French adverbials of date (*cf.* Maurel D. 1988 & 1990a) and to deal with them using finite state automata (*cf.* Maurel D. 1990b&c). I have written a program which recognizes these adverbs on a PC. It can recognize forms of the type: *dans trois jours* (*in three days*), *vers la fin de la semaine prochaine* (*towards the end of next week*), *le lundi 29 février* (*monday the 29th february*), *etc*

1. Automata and tables of acceptability

1.1. Lexical automata

When representing *Kleene Grammars*, we use operators for concatenation, disjunction and iteration, as well as the empty symbol (<*E*>). The set of all possible constructions has thus been studied using all the lexical terms for date adverbials. I shall illustrate this by constructing a *Kleene grammar* for four prepositions (*à*, *à partir de*, *dans* and *en*) and six nouns of time (*matin*, *matinée*, *semaine*, *printemps*, *été* and *siècle*), and with the insertion of a definite article.

(1) Preposition Time noun

* *L'accident a eu lieu (à + à partir de + dans) (matin + matinée + semaine + printemps + été + siècle)*

*L'accident a eu lieu en (*matin + matinée + semaine + *printemps + été + *siècle)*

lit. *(The accident happened (at + from + in) (morning + morning + week + spring + summer + century)*

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1 Laboratoire d'automatique documentaire et linguistique, University Paris VII.

(2) Preposition Article Time noun

La convention aura lieu à partir de (le matin + le printemps + l'été)

La convention aura lieu à partir de (la matinée + la semaine + le siècle) (<E> + prochain(e))*

La convention aura lieu au matin (?<E> + du 29 février)

* *La convention aura lieu à (la matinée + la semaine) (<E> + prochaine)*

La convention aura lieu au printemps

La convention aura lieu à (l'été + le siècle) (<E> + prochain)*

* *La convention aura lieu dans le matin (<E> + du 29 février)*

La convention aura lieu dans (la matinée + la semaine + l'été+ le siècle) (<E> + prochain(e))

? *La convention aura lieu dans le printemps (<E> + prochain)*

* *La convention aura lieu en (le matin + la matinée + la semaine + le printemps + l'été+ le siècle) (<E> + prochain(e))*

lit. *The convention will take place in the (<E> + next) (morning + morning + week + spring + summer + century)*

These examples show that these four prepositions constitute four distinct classes, in other words four distinct transitions towards differents states as showed in *figure 1*.

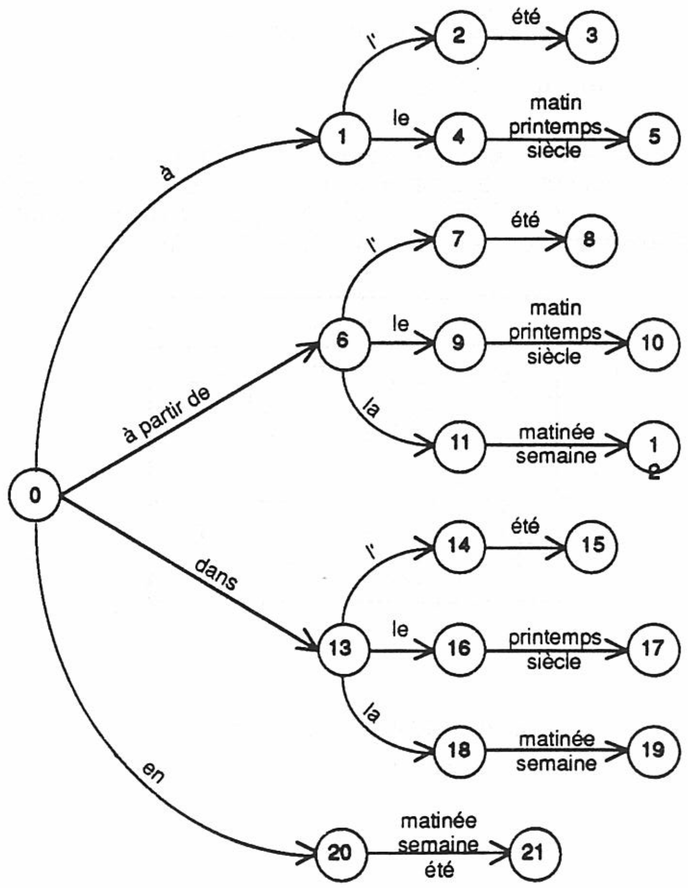


Figure 1: a lexical automaton

If we are no longer considering four prepositions and six time nouns, but also twenty prepositions, thirty-four time nouns and about ten simple determiners the picture becomes even more complex! Then by adding more determiners, adverbs, nouns, adjectives, prederterminers, modifiers, *etc.* the automaton becomes almost impossible to implement "by hand", and particulary impossible to modify, correct or custom for any particular application. However, being able to complete the initial study using the existing results appears to be an important quality for this type of system. This is why I have defined another model for representing the data, wich is made up of automata and tables of acceptability.

1.2. Class automata

Instead of using lexical entries as labels for different transitions on the automaton, I defined morpho-syntactic or semantic classes and built an automaton where the transitions are labelled as classes. This gives us the advantage of being able to greatly reduce the number of states and also gives us a realistically sized automaton, apt for linguistic applications.

In the above example, we define three classes:

<Prép>={à, à partir de, dans, en }
<le>={le, la, l'}
<Ntps>={matin, matinée, semaine, printemps, été, siècle}

which gives us the automaton in *figur 2*:

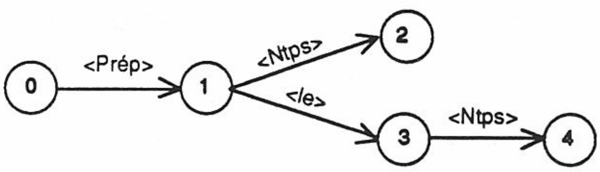


Figure 2: a class automaton

1.3. Tables of acceptability

Of course, the automaton in *figure 2* does not correspond to the grammar that we have defined in 1.1, since all inacceptabilities have been eliminated! This automaton therefore recognizes too many combinations. This is why we must join a table of acceptability which completes the information we require. It is a binary matrix (*cf.* Gross M. 75). See *figure 3*.

Avoir lieu												
<Prép>	matin	matinée	semaine	printemps	été	siècle	le matin	la matinée	la semaine	le printemps	l'été	le siècle
à	–	–	–	–	–	–	+	–	–	+	+	+
à partir de	–	–	–	–	–	–	+	+	+	+	+	+
dans	–	–	–	–	–	–	–	+	+	+	+	+
en	–	+	+	–	+	–	–	–	–	–	–	–

Figure 3: a table of acceptability

2. Automata for dates, hours, time nouns, time adverbs and holiday dates.

All my work on dates and date adverbials has led to me building (using this mode) five automata wich handle time adverbs (*figure 4*), dates (*figure 5*), holiday names (*figure 6*), hours (*figure 7*) and time nouns (*figure 8*):

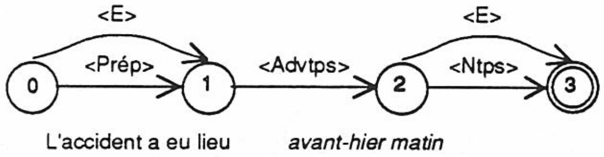


Figure 4: automaton for time adverbs

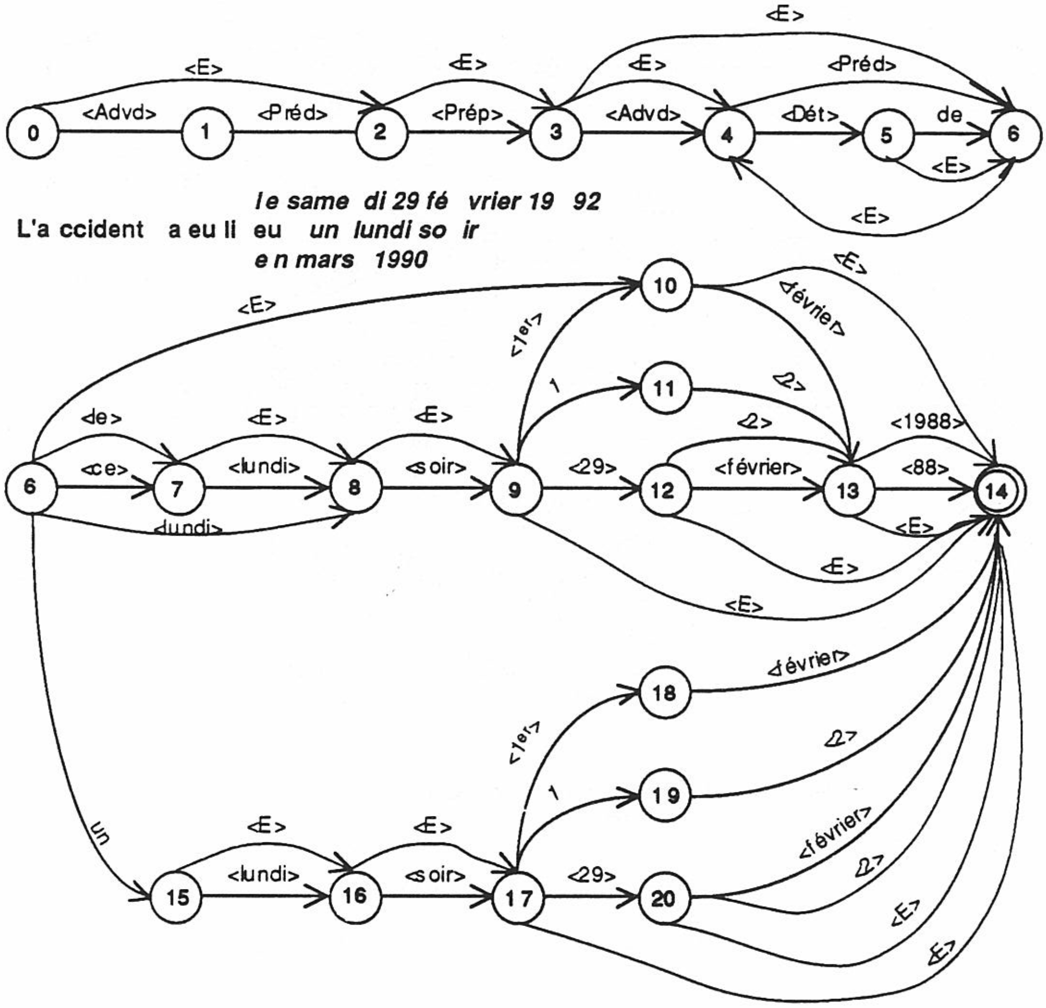
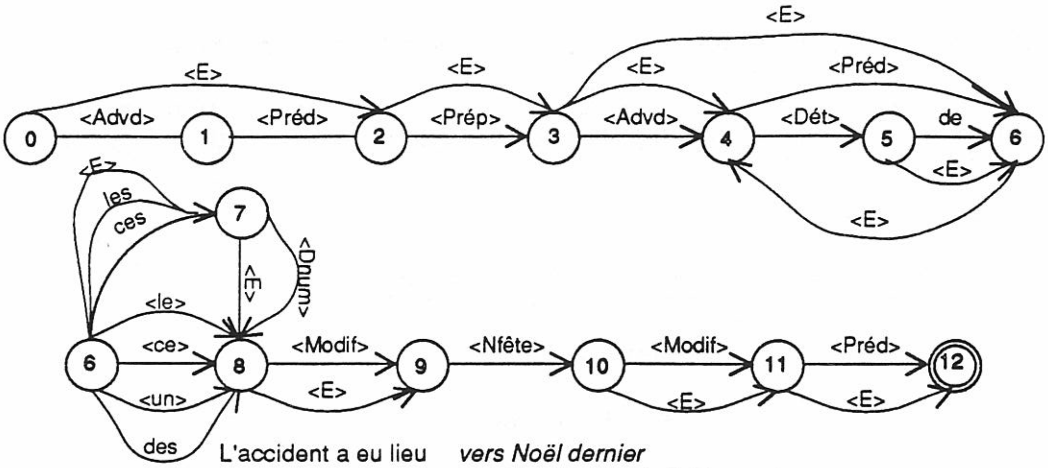
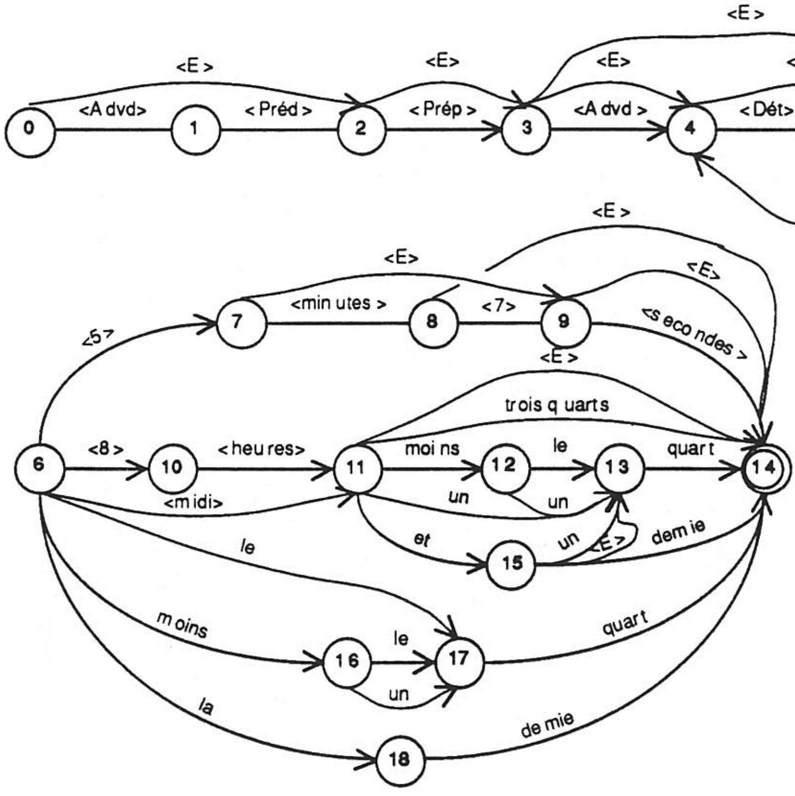


Figure 5: automaton for dates



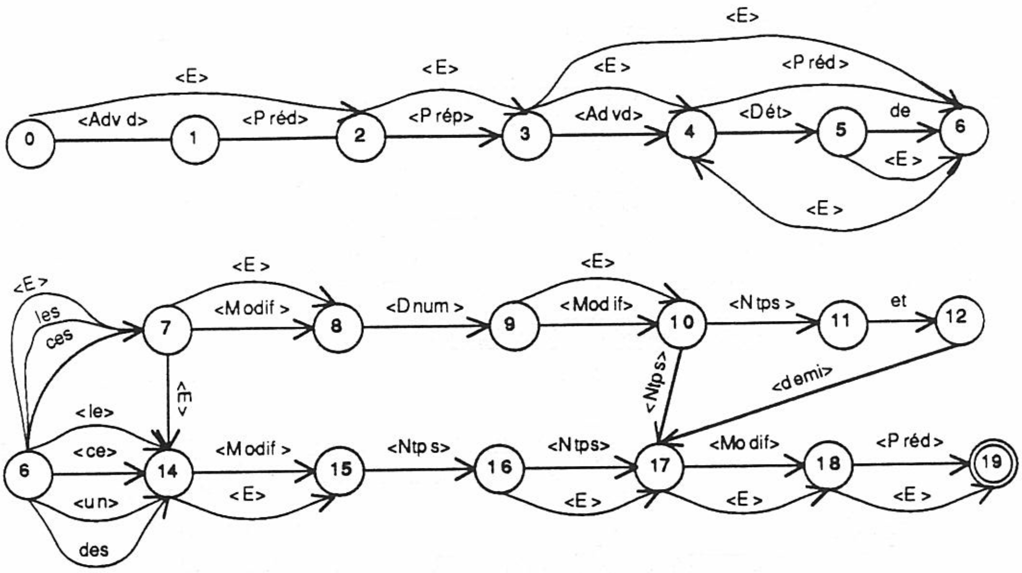
L'accident a eu lieu *vers Noël dernier*
pendant le pont de la Toussaint

Figure 6: automaton for holiday names



L'accident a eu lieu *à 8 heures 3*
avant midi moins le quart
après la demie

Figure 7: automaton for hours



L'accident a eu lieu *à peu près vers la fin de la semaine dernière*
depuis presque trois jours et demi
dans les années 80

Figure 8: automaton for time nouns

These automata have been grouped together in one single deterministic automaton. It contains fourty-four states and two hundred and seventy-seven transitions. It comes together with heigty-two tables of acceptability (*cf.* Maurel D. 1989).

3. Program presentation

How the program works is shown on the organigram in *figure 9*. Some things however need to be explained, especially regarding the first phase at reading and recognising the word themselves (§3.1-3.3). Then I shall present the coordination processing (§3.4), and then the use of the automaton and the tables (§3.5).

3.1. The reading of a word

A word is first of all looked upon as a sequence of letters or figures; the non alphanumeric caractors which follow are memorised as separators. Then, to allow us to recognize compound words such as:

> *week-end* (with hyphen)
> *aujourd'hui* (with apostroph) (*to day*)
> *à partir de* (with spaces) (*from*)

several words are read in succession before consulting the dictionary.

A preliminary processing procedure discords certain words according to their spelling when this is uncompatible with an adverbial of date:

1) To be accepted, a sequence of letters must be written completely in lower cases or completely in upper cases or must begin with an upper case then followed by lower cases:

> *demain* (*to morrow*)
> *DEMAIN*
> *Demain*

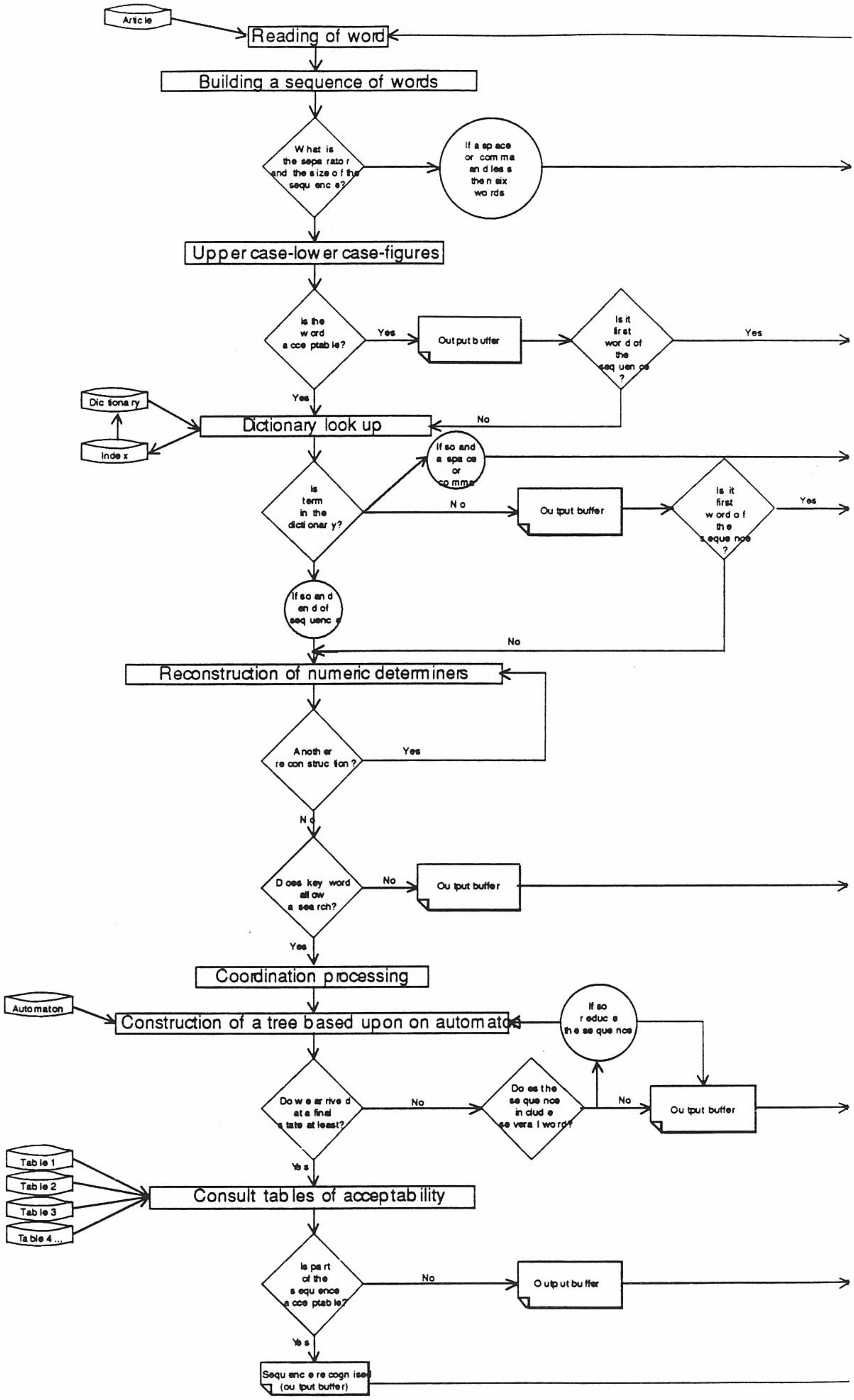


Figure 9: the organigram

However , before elimination, we must check that it is not an ordinal numeric adjective written in Roman numerals, as:

XIX$^{\text{ème}}$ siècle (XIX$^{\text{th}}$ century)

(2) A sequence of capital letters can be a number written in Roman numerals. This obviously does not appear in the dictionary; so we assign a code to it, according to its numeric value.

However, some sequences are ambiguous:

L -> 50 or *l* (*the*)
D -> 500 or *d* (*this*)
CI -> 101 or *ci*
DIX -> 509 or *dix* (*ten*)
MI -> 1001 or *mi* (*middle*)

Nevertheless, except for *DIX*, which is surely a rare Roman number, these ambiguous sequences are easily solved by the presence or absence of an apostroph or a hyphen.

3) In order to be accepted, a sequence of arabic figures must be written only in figures, exepted for:

1$^{\text{er}}$, 1$^{\text{ère}}$
2$^{\text{nd}}$, 2$^{\text{nde}}$
2$^{\text{ème}}$, 3$^{\text{ème}}$, ...
7$^{\text{bre}}$, 8$^{\text{bre}}$, 9$^{\text{bre}}$, 10$^{\text{bre}}$ [2]

Like for Roman numerals, a code is linked to every number, according to is value, in order to know whether it corresponds to times of day, days of month, *etc.*

3.2. Dictionary look up

The dictionary look up, using an index, allows us to link dictionary data from DELAF[3] to each word. We also use a code which indicates its morphosyntactic or semantic[4] class when the automaton reads the word.

For words wich include one or more upper case letters, the look up is done under the same format to allow for any ambiguities that arise:

DES -> des or *dès*[5] (*of the* or *since*)

The reading continues as leng as words are accepted according to their format and the dictionary look up.

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2 Ce sont des anciennes abréviations pour *septembre*, *octobre*, *novembre* et *décembre*.

3 This is done for the dictionary at LADL. Any other dictionary could be used to provide information, *e.g.* when using another system for textual analysis.

4 In the example given in 1.2, we deal with the class of prepositions, *<Prép>*, that of definite articles, *<le>*, and nouns of time, *<Ntps>*.

5 *dés* (*dice*) could be included, but this word is not a part of a date adverbial.

3.3 Reconstructing numerical determiners

The dictionary only contains numerical determiners (cardinal or ordinal) as single words. Any other numerical determiners are reconstructed at this stage and are assigned a suitable code. The reconstruction consists of two parts:

1) Recognising each single word using a lexicographic automaton with multiple terminals wich links each final state with a numerical value (see *figure 10*)

2) An algorithm to calculate the numerical value of a particular sequence

Several reconstructions can occur when we are dealing with a date adverbial. official document for example often contain dates written completely in letters:

> Le vingt-neuf février mil neuf cent quatre-vingt-douze
> (*The twenty ninth of february nineteen ninety two)*

he following stage is only performed if there is a key word: time noun, hollyday names, a number, *etc.*

3.4. Processing conjunctions of coordination and complex prepositions

Conjunctions of coordination (*et, ou, ni, ... - and, or, nor,...*) and complex prepositional forms like *entre---et* (*between--and*) ou *de---à* (*from--to*) both the same rules for factorisation as in sentence (1) and (2) below:

(1) *Le séminaire a eu lieu le 29 et le 31 octobre 1990.*
The seminar took place on the 29th and 31st of October 1990.

(2) *Le séminaire a eu lieu du 29 au 31 octobre 1990.*
The seminar took place from the 29th until 31st of October 1990.

where *October 1990* is related to both the 29th and 31st.

This type of factorisation applies to any part of the adverb: date, time noun, modifier, determiner, *etc.*, as shown in the previous examples and in the sentences (3) and (4):

(3) *Le séminaire aura lieu dans les trois ou quatre jours à venir.*
The seminar will take place over the next three or four days.

(4) *Le séminaire aura lieu vers le milieu ou la fin du mois de mars.*
The seminar will take place around the middle or end of March.

In sentence (3), *three or four* applies to *next days*, wich is factorised; in sentence (4), it is *the middle or end* wich applies to *March.*

Also, these adverbs can be made more complex if we use commas to co-ordinate more then two terms:

(5) *Le séminaire a eu lieu le 29, le 30 et le 31 octobre 1990.*
The seminar took place on the 29th, 30th and 31st of October 1990.

(6) *Le séminaire aura lieu dans les deux, trois ou quatre jours à venir.*
The seminar will take place over the next two, three or four days.

And this may be the case without any limit on the number of factors, as shown in sentences (7) et (8):

(7) *Le séminaire a eu lieu les 26, 27, 28, 29, 30 et 31 octobre 1990.*
The seminar took place on the 26th, 27th, 28th, 29th, 30th and 31st of October 1990.

(8) Le séminaire aura lieu dans les deux, trois, quatre, cinq, six ou sept jours à venir.
The seminar will take place over the next two, three, four, five, six or seven days.

However, notice that the factorised term may be place to the left or the right of the expression:

(9) *Le séminaire aura lieu en janvier, février et mars 1991.*
The seminar will take place in January, February and March 1991.

(10) *Le séminaire aura lieu en janvier 1991, 1992 et 1993.*
The seminar will take place in January 1991, 1992 and 1993.

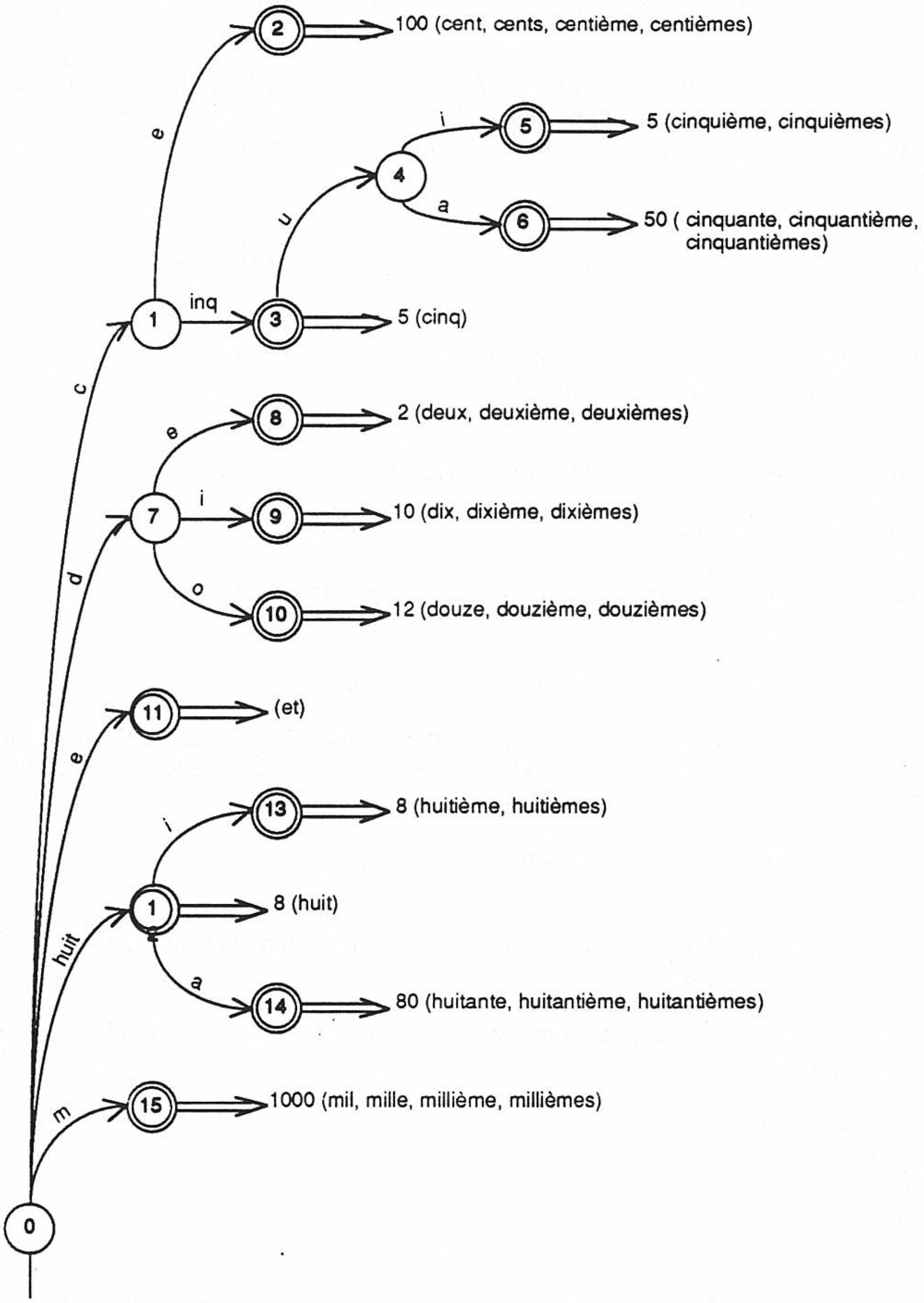

Figure 10: lexicographic automaton with multiple terminals

In the sentence (9), 1991 is factorised by the terms *January, February and March* to its left, whilst in sentence (10), *january* is factorised by the terms to its right, *1991, 1992 and 1993.*

Furthermore, the factorisations may also be built upon each other, as in sentences (11) and (12):

(11) *Le séminaire aura lieu les vendredi 31 mai et samedi 1er, dimanche 2 juin 1991.*
The seminar will take place on Friday 31st May and Saturday 1st, Sunday 2nd of June 1991

(12) *Le séminaire aura lieu les jeudi 30 et vendredi 31 mai et samedi 1er juin 1991.*
The seminar will take place on Thursday 30th and Friday 31st May and Saturday 1st of June 1991

In sentence (11), *1991* operates on *May* and *June* which itself is factorised by *Saturday 1st, Sunday 2nd*. In sentence (12), *1991* operates on *May* and *June*, but the second factorisation is *May* wich applies to *Thursday 30th and Friday 31st.* Finally, we come to even more complicated sentences like sentence (13):

(13) *Le séminaire aura lieu les 29, 30 et 31 mai et les 1er, 2 et 3 juin 1991.*
The seminar will take place on the 29th, 30th and 31st of May and the 1st, 2th and 3th of June 1991.

When there is a conjunction or a complex preposition, an analysis of the various possible ffactorisations is made using a metagrammar of rewriting rules. These factorisations are then provisionally ignored before being dealt with the automaton.

For example, the adverb in sentence (11) would be analysed to follows:

(14) *les vendredi 31 mai et samedi 1er, dimanche 2 juin 1991*

-> *les <Njours> <Djours> <Nmois> <Conj> <Njours> <Djours>, <Njours> <Djours> <Nmois> <Dannée>*

-> *les <Njours> <Djours> <Nmois> <Dannée>*

This is the only structure which is passed on to the automaton. Of course, the fact that the other factorisations will be noted and will therefore be passed on when a complete syntactic analysis is made of the text.

3.5. Use the automaton and tables

When we use the automaton, a tree of all possible paths is built up (until we reach a final state). If the analysis fails, the first word is eliminated and this new sequence of words is then passed on to be analysed again.

This process can be repeted several times when we are dealing with prepositional complements such as:

Le 3 janvier au soir
On the 3rd January in the evening

Le cinquième jour de la troisième semaine du mois
The fifth day of the third week of the month

which are recognised in two or three consultations respectively. Any sequence which consists of several adverbs is then marqued and this information can be finally passed on to a syntactic analyser.

If the whole of the sequence is not recognised, then that particular part which is unknown is memorised, and the analysis then continues by consulting the tables of acceptability.

To keep in line with the binary structure of the tables, they are consulted in a special order, from the most particular words to the more general ones. First, the dates looked at, then modifiers, determiners, prepositions, *etc.* A sequence (or part of a sequence) which is recognised by the automaton, but the acceptability of which is not verified on the tables, is then eliminated.

Naturally, a sequence of words that has already been recognised comes with it all the information it has aquired during the analysis, as well as the infomation taken from the dictionary. The program that curently exists stops here. I remind you that the aim of this work is to combine our preanalysis with the dictionary look up of a syntactic analyser. For certain sequences of word, this analyser would be provided with further information taken from a dictionary, information similar to that of *date adverbial* (with its structure) and would be able to use this data right from the start of an analysis.

4. Sample Texts

4.1. Extract from Le Monde newspaper 4th May 1988

«Trois mille ouvriers des chantiers navals Lénine de Gdansk, où, ***en août 1980 (in August 1980)***, une grève menée par un électricien nommé Lech Walesa devait donner naissance à Solidarité, se sont joints, ***le lundi 2 mai (on Monday 2nd May)***, à la série d'arrêts de travail lancée ***une semaine plus tôt (one week earlier)*** par les conducteurs d'autobus de Bydgoszcz... Le mouvement de protestation ouvrière contre la hausse des prix, le plus sérieux auquel ait été confronté le général Wojciech Jaruzelski depuis la dissolution de Solidarité ***en 1982 (in 1982)***, prend donc maintenant un tour hautement symbolique. ***Dans la matinée de lundi (on Monday morning)***, deux cents ouvriers ont défilés dans l'enceinte des chantiers naval de Gdansk, qui emploient douze mille personnes, en exhortant les travailleurs à une grève de solidarité avec ceux de Nowa-Huta. ***En fin de matinée (Towards the end of the morning)***, un millier d'hommes cessaient le travail. ***En fin de journée(at the end of the evening)***, ils étaient trois mille... »

4.2. Extract from Le Monde newspaper 21th February 1989

«C'est un porte-parole, et non pas M. Najibullah lui-même, qui a lu, ***samedi soir 18 février (Saturday night on the 18th February)*** à la télévision et à la radio, la déclaration présidentielle annonçant la proclamation de l'état d'urgence sur toute l'étendue du territoire. Cette décision, entrée en vigueur ***le 18 février à 0 heure (on the 18th February at midnight)***, avait été précédée ***dans l'après-midi (in the afternoon)*** par une activité militaire inhabituelle dans les rues de la capitale.... Une promenade effectuée ***en fin de soirée (at the end of the evening)*** permettait de constater que les rues étaient désertes, curieusement éclairées par un très beau clair de lune et par le reflet étincelant des collines enneigées... Les abords du palais présidentiel étaient étroitement gardés, mais, dans une ville ultra-militarisée ***depuis dix ans (for ten years)***, ces mesures n'avaient rien d'ostentatoire...***Dans la journée du 19 (during the day of the 19th)***, une douzaine de blindés, dont quelques chars lourds, étaient visibles aux endroits stratégiques, et les patrouilles étaient plus nombreuses qu'à l'accoutumée...***Le 18 (on the 18th)***, le porte-parole du ministère des affaires étrangères avait solennellement prévenu la presse internationale qu'il était interdit de s'approcher, de prendre des photos ou de filmer des blindés...»

4.3. Extract from Le Monde newspaper 18th February 1989

«Il [le drapeau] orne les bannières, s'arrache en petit format pour trois roubles, s'agite au bout des bras et, ***dès mercredi soir (since wednesday night)***, dans le grand théâtre de Kaunas, l'ancienne capitale royale, il est lentement descendu sur scène, pendant que s'élevait l'hymne national, l'hymne de l'indépendance, chant grave et lent que seuls les kamikazes s'avisaient, il y a peu, d'entonner. Alors, dans cette petite salle italienne aux fauteuils tendus de velours violet, toute l'élite lituanienne s'est levée, messieurs barbus et dames en robes longues, les larmes ont perlé à bien des yeux et l'on se serait cru ***au dix-neuvième siècle (in the nineteenth century)***, à Budapest ou à Milan, quand l'empire austro-hongrois se lézardait et que la bonne société conspirait à l'Opéra...

En quatre mois (in four months) d'existence légale, ce mouvement a imposé un double pouvoir en Lituanie... Il [Romualda Ozolas] ajoute que "***dans cinq, dix ou quinze ans (in five, ten or fifteen years)***", il verra la Lituanie indépendante... ***Depuis des décennies (for decades)***, ce monument à l'indépendance avait été relégué dans un musée... Un vieil homme a dormi à ses pieds ***plusieurs nuits d'affilée (several nights in succession)***...

On dit M. Brasauskas objet d'une formidable pression de Moscou à ce sujet, mais il tiendrait bon, d'autant qu'il a été mis en place ***en octobre dernier (last october)*** par l'équipe Gorbatchev, qui n'a guère d'autre carte locale...»

4.4. Extract from Le Monde newspaper 9th August 1987

«Il faut être en vacances pour s'intéresser à son emploi du temps, ont dû penser les statisticiens de l'INSEE qui viennent de publier... un minutage très précis de nos activités d'après une enquête réalisée ***en septembre 1985 et octobre 1986. (in September 1985 and October 1986) Depuis dix ans (for ten years)***, date de la précédente consultation à ce sujet, les adultes citadins(1) ont surtout gagné du temps libre, ***36 minutes par jour (36 minutes each day)*** en moyenne...Hormis le temps passé à table... les autres séquences demeurent relativement stables ***sur dix ans (over ten years)***. Le temps "physiologique" passe de ***12 h 05 à (to) 11 h 53***... Pour les femmes actives, le temps de travail représente ***32 heures par semaine (32 hours per week)*** et les trajets ***3 h 30***. Globalement, les femmes travaillent cependant plus longtemps que les hommes à cause des activités domestiques (***4 h 30 par jour (4 h 30 each day)***). Ces tâches accaparent les femmes au foyer ***entre 7 h 12 et 8 h 12 par jour (between 7 h 12 and 8 h 12 each day)***, selon leur âge, c'est-à-dire qu'elles exigent plus de temps qu'une occupation professionnelle...

Le rural travaille... ***jusqu'à 8 h 19 par jour (until 8 h 19 each day)*** pour l'agriculteur, sa femme étant absorbée ***pendant 6 h 15 (for 6 h 15)*** par les travaux domestiques, difficiles à distinguer dans l'activité d'une ferme... Manger y est encore un cérémonial qui occupe l'agriculteur ***pendant plus de 2 heures (for more than 2 hours)***... On verra ***dans dix ans (in ten years)***, lors de la prochaine enquête, si l'influence des citadins modifie leurs comportements.»

5. Conclusion

As explained above in 3.5, a preanalysis of this nature should complement a syntactic analyser when dictionary look up is involved. In fact, a simple look up can create different sorts of problems (as listed in the introduction or the ones we mentioned in 3.2) generally due to a continuum between single words, compound words and fixed expressions (*pipe, pipe-line, casser sa pipe...*). Where exactly is the line drawn between dictionary look up and analysis? A preanalysis similar to the one described here seems a good solution, it even allows us to add a procedure for recognising more complex sequences, like *date adverbials.*

Naturally, the preanalysis must serve two purposes: firstly, to recognise the sequence, and, on the other hand, to maintain data on the single words. This problem is illustrated in the two folowing sentences:

(15) *Dans son club de poterie, Jean a réalisé une pomme de terre cuite.*

(16) *Ce maigre repas était constitué d'un seul plat: une pomme de terre cuite.*

In sentence (15), the words are *pomme (apple)* and *terre cuite (pottery)*, whilst in sentence (16), the words are *pomme de terre (potato)* and *cuite (cooked)*. This problem of ambiguity even exists for dates, as in examples (17) and (18):

(17) *Vers la fin de l'après-midi du dimanche 3 voitures étaient garées sur ce parking.*

(18) *Vers la fin de l'après-midi du dimanche 3 ces voitures étaient garées sur le parking.*

where sentence (17) includes the adverb *Vers la fin de l'après-midi du dimanche (toward the end of Sunday afternoon)*, whilst in sentence (18), the adverb is *Vers la fin de l'après-midi du dimanche 3. (toward the end of Sunday afternoon, the 3rd)*. The analyser is called to choose between the two solutions depending on whether a determiners appears before the word *voitures* or not.

It could also also be the case that the whole of the sequence has to be reinterpreted by the analyser, as in examples (19) and (20):

(19) *Jean a pris une veste car (il fait froid + il s'est mal comporté).*

(20) *J'appelerai le 11 car (aujourd'hui je n'ai pas le temps + je n'ai pas son numéro de téléphone*[6]*).*

where the ambiguity cannot be solved at a lexical level.

Nevertheless, the analyser identifies between what we call a date adverbial an a real temporal adverb, or which defines its real syntactic function as shown in (21), (22) and (23):

(21) *L'accident s'est produit le 29 février 1988.*

(22) *Le 29 février 1988 restera le plus beau jour de ma vie.*

(23) *On nous avait seulement accordé le 29 février 1988 pour nous reposer.*

where *Le 29 février 1988 (the 29th February 1988)* respectively is a temporal adverb, a subject and a complement of a direct object. We have not yet mentioned the different semantic interpretations that arise depending on whether the date is understood as having a ponctual or a long team meaning.

The lexicon and the number of forms accepted by the automaton are also going to be extended in the near future. Presently, I have three applications of this work:

This analyser is being implemented for an automatic indexing system for texts at LADL (*Cf.* Silberztein M. 1990). A program for automatically converting the automaton and the tables of acceptability into one automaton with labelled transitions using single word is currently being developed.
For the query of data base in Natural Language, a program is developed at Nantes about the question: "When do you want to take train?". After the preanalyse of the answer, an interpretation is calculated before the interrogation (*Cf.* Bernard P. 1992).
Also, i,n conjunction with IRIT[7], we aim to build a system which can perform semantic analysis of temporal structures in texts. For this task, the automaton will be transformed into a multiterminal automaton which labels adverbs using the classification developed at Toulouse by Molinès F. 1989. Then this preanalysis will be followed by a technique for analysing texts developed by Bras M. 1990; she build a temporal representation of the text by applying semantic calculations on the adverbials and on the tenses of verbs.

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[6] In France, 11 is the directory enquiries number.

[7] L'Institut de Recherche en Informatique de Toulouse (Toulouse Computer Science Research Institute).

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"Ce matin, il pleuvait" ou la référence à l'épreuve du temps

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1. Introduction.

In this paper we will be mainly interested in studying some French temporal clauses such as *le matin (the morning)*, *ce matin (this morning)* and their referential abilities. This might be surprising for researchers whose field remains the study of the phenomenons implied in the launching of man-machine dialogue systems. Such a discrepancy can be explained in two ways. Firstly, one of the most important problem raised by the launching of a man-machine dialogue is to resolve references, that is to say- at least the way our community understands it[1] - to find the objects the user is talking about in order to fulfill his will concerning a particular task. In this scope, temporal phrases, for instance, though not often used in the task driven dialogues, enjoy an important referential meaning and develop themselves along a particular dimension. They represent a kind of experimental melting pot in which some of our hypothesis can be tested. On the other hand, the temporal dimension which is here displayed is particularly important in the field of task oriented dialogues. Indeed, their goal is the evolution of objects in a task. We will come across utterances such as *mets cette fenêtre en vert (colour this window in green)* followed by *déplace la fenêtre qui était verte (shift the window which was green)*. Then we should be able to represent these transformations as well as their consequences. So we must have a particular model in order to integrate our systems in time, here again, temporal phrases can be a means to test such a model.

The double concern we have for reference and time seems to express itself through temporal phrases which draw a frame for the analysis of other referential clauses which can be found in a discourse. Moreover we shall see that resolving referential phrases also implies the treatment of the predicative frame in which they fit.

In a sentence such as *nous arrivâmes dans un village (we arrived in a village)*, the village in question - apart from actually being a village - possesses the property to be the one in which we arrived. It already breaks away from the prototype attached to the lexeme village. It seems that *un matin (one morning)* in *un matin nous arrivâmes dans un village (one morning we arrived in a village)* can be analysed in a more autonomous way. In this scope, temporal phrases as well as many peripheral constituant are good examples for a simplified analysis of reference phenomenons.

At this stage we can ponder over the methodology to be used when working on long term projects which aim is to launch language comprehension systems. These are not bound to the mere analysis of phrases such as *la semaine dernière (last week)*. We cannot afford to give only a specific explaination to these phrases. This would lead us to implement a specific procedure and to progressively build a patchwork system with no global coherence. So we are constantly obliged to propose relatively general models which widely cover the utterances we may encounter, eventhough some of these models may not fit "limit cases" raised by the linguist. The advantage of this method is that it allows us to understand the ground of one or another reaction of our systems in a real situation whereas the multiplicity and incompatibility of the models often prevents our studies from progressing.

First we shall present a particular frame for the analysis of referential phrases (Gaiffe 1992). Then, we shall display the principal basis of a time and object representation model that we developed in our team for the peculiar needs of man-machine dialogue (Romary 1989 and 1991). At last we shall try to synthesize these two approaches in the frame of temporal phrases.

1.1 The reference problem

In the field of man-machine dialogues, and above all when multimodal dialogues[2] are concerned, the problem of reference resolution can be approached from two different ways. The first case is the one of

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[1] Along this article we shall see why this vision is particularly limitative.

professional users who would accept to submit themselves to a training period and also when the application is simple enough. In this diagram the most efficient approach is to define an artificial language such as the ones created to launch an electronic letterbox (Morin 1987) or a sonar console (Souvay 1992). In those situations the language is defined in order to ease the resolution of the references expressed by the user.

However in other cases we cannot procede in this way. Indeed, we know (Deville 1989, Falzon 1984 and 1990) that the dialogue is oriented towards the task, consequently the language which is to be treated corresponds to a sub-language which is commonly referred to as natural language. It appears however, that whatever the task is, it is impossible to obtain a reduction of the palette of referential phrases generally used. That is to say the definite, indefinite, demonstrative or pronominal phrases. The restrictions we can observe are rather situated at the level of relevant concepts for the task and lead to the reduction of the lexicon and of the semantic value of its entries. the choice we made is to consider referential phrases such as they are used in the current language (i-e natural language) and to bet they will be used the same way in a task oriented dialogue rather than trying to imagine the reactions of the user of a dialogue system and to limit our implementations to this narrow view (which often is a nonsense).

In order to exemplify this point, let's have a look at a few phrases which can be treated in a windowing environment.

(a) iconifie la fenêtre. *iconify the window*

(b) agrandis cette icône (avec un geste de designation). *widen this icon,* *with pointing gesture*

(c) transforme la fenêtre rouge en icône et met (d)cette icône prés de l'horloge (sans geste de désignation) (*turn this red window into an icon and shift this icon next to the clock without pointing gesture.*)

(e) crée une nouvelle fenêtre de texte. *(create a new text window)*

(f) mets la ici accompagné d'un geste *(put it here with pointing gesture)*

Through these exemples we can observe what our fellow linguists call anaphoras (b: la fenêtre; the window; d: cette icône; this icon; f: la; the) which compell us to take in account the previous utterances and the deictic phrases (f: ici here) which are on occasion accompanied by a pointing gesture and direct references (a: la fenêtre verte; the green window). We can point out as many other did (Wilmet 86, Corblin 1987, Kleiber 1991) that the behaviour of a demonstrative phrase is not necessarily situated in an homogeneous category and that a pointing gesture made by the user is not always to be awaited for. Though it may be tempting (to simplify an implementation) to set up such restrictions and to forbid the use of anaphoras and demonstratives. A general analysis of the references phenomenons compells us to give up these choices. Otherwise we would conceive tailor-made systems for the application we aim at.

1.2 Approaches ensuing from a naïve logic

In the field of man-machine dialogues, since the application is generally not very complex, the resolution of references most of the time hinges on what we can call a naïve logic. In a few words, it is assimilating the search of a referent associated to a phrase such as la fenêtre (the window) to the search among the objects of the task of an element submitted to the constraint 'fenêtre(?x)' 'window(?x)' (predicative form associated to a linguistic phrase). It is only when such a procedure fails, that is to say when there isn't a single element which fits the constraint, that an anaphoric interpretation of the nominal phrase is considered. The anaphoric resolution is then made by scanning the story of the dialogue, looking for an element which fits the constraint previously utterred. In a way it can be said that such an approach is based on a test of pragmatic incompleteness of the nominal phrase[3] . To solve the problem raised by pronouns, we use a similar mechanism: the pronoun (give or take the genre and number constraints) can be associated to any object in the task. So, if more than one object is to be found in the task (which is naturally often the case) the referent is obtained thanks to discourse memory.

If demonstratives are introduced in such systems (for instance in a multimodal context) we obtain a relatively similar mechanism. If a gesture is observed, it is used in association with the nominal phrase in the

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[2] That is to say dialogues in which different ways of communicating such as gesture or speech intervein.

[3] Milner describes the pronoun as being deprived of virtual reference. We then face a semantic incompleteness. In our case it is indeed a pragmatic incompleteness since a parameter is lacking to call a function of the task.

current utterance. Otherwise, as in the case of definite descriptions, the search is made by anaphoric lack (by a search in the story of the dialogue) (Neal 1988).

If we consider the whole range of possible phrases - un N, a N, le N, The N, ce N, This N - they are all associated to a constraint expressed as N'(?x) in which N is a thing wich is kin to the class of objects which can be called N (In the case of the pronoun, it is the class of all the objects which associated noun fits the number and genre constraints). In this way, and this is why we qualify this logical approach as naïve, we evacuate the specific properties of the French determinants (or English for corresponding works) whereas it is clear that each of them has a working principle which must be analysed.

This can be shown easily in the following exemples, where it is obvious that the sentence (2') is acceptable in the context of (1) whereas (2) is not.

(1) déplace la fenêtre verte et l'icône bleue. *(shift the green window and the blue icon)*
(2) iconifie cette fenêtre. *(iconify this window)*
(3) iconifie la fenêtre. *(iconify the window)*

More precisely, if there is still a doubt concerning the fact that a pointing gesture has or has not been made - and if the utterance given is (2) - we will rather acknowledge that a gesture has been made[4] . On the contrary, in the context of speech recognition and provided we can be sure that no pointing gesture has been made, we will consider that (2) is not a good hypothesis for recognition in the case of an oral dialogue system.

The conclusion we can draw from these approaches is that wanting to know whether the phrase is an anaphora or not is not a good way to handle the problem. Indeed as it is impossible to take a decision concerning the anaphoric character of a phrase before the actual referent has been found, it is useless to manipulate two different hypothesis which will anyway lead to the same computed set. Another option is to base the computed set on a steady ground which would integrate the datas directly available from the utterance as a whole. This is why we try to propose an unified analysis for each type of determinant (definite, indefinite or demonstrative) that can be found in a nominal phrase. Moreover, as we know that the interpretation of a pronoun mainly depends on the nature (definite, indefinite or demonstrative) of its antecedent in the dialogue, we only consider those in the frame of a sufficient explanation of the other type of referential phrases.

1.3 Defined descriptions

We try to obtain an homogeneous description of the definite nominal phrase, whether it is or not anaphoric. There is one certainty about these phrases, it is that the associated referent must be found within a set[5] . For instance, the search for the referent associated to la fenêtre (the window) can be made within the set of objects appearing on the user's screen. Other types of sets can be drawn according to the utterances preceding the current utterance. In this case there will actually be an anaphoric resolution of the definite nominal phrase. At this stage, we notice that the comparison between the applicant referent and the operation of reference has been replaced by the creation of sets and their comparisons.

Let's have a look for instance at the following utterances:

(1) déplace la fenêtre verte et l'icône bleue; *(shift the green window and the blue icon)*
(2) agrandis la fenêtre.*(widen the window)*

The reference corresponding to the window can be resolved in one of the following set

- the set of objects which can be seen by the user. (S1)
- the set - created by the discourse - containing the green window and the blue icon (provided the references have been correctly resolved in the frame of utterance 1): (S2)

The argument which leads us to choose S2 rather than S1 is that S1 is going to contain more than one window. Actually the sets considered are sets of objects. So S2 does not contain the description of each object. That is to say neither information concerning the words used to refer to these objects, nor any halfway result from their analysis are part of the description of the set. S2 contains the object (for a dialogue system: The

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[4] The generalized use of the mouse could make us think that a pointing gesture is never ambiguous. With a glove, however, we can never be sure wheter a gesture has actually been made or not.

[5] This notion will become meaningful later on. It is by no mean a 'hard' mathematic concept.

description of its computed set) resulting from the referential analysis of the phrase la fenêtre verte *(the green window)* as well as the one resulting from the analysis of l'icône bleue *(the blue icon)*. Consequently, S1 and S2 are kin ontologically speaking: they are detached from the linguistic origin which may or not have led to their creation.

As a criterion for the choice of one or another set we have mentioned that there is one and only one object which fits the description in the applicant set. Another important criterion is that the set must contain at least one object which does not fit the description. Consequently in our exemple, the set S2 was a good applicant because it contained an object which was not a window.

Such a criterion, though it might seem at face value arbitrary, enables us to explain the following exemple and its like.

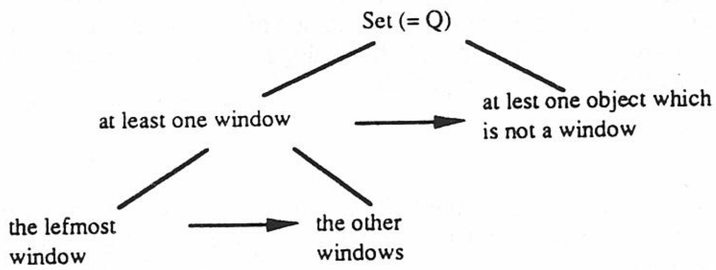
(1) déplace la fenêtre verte et la rouge *(shift the green and the red window)*

(2) agrandis la fenêtre la plus à gauche *(widen the window which is the most on the left)*

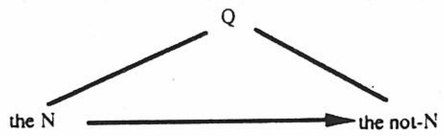
Since the set which contains the associated referent to la fenêtre verte et la rouge *(the green and the red window)* contains only windows, we will rather choose here the set of objects which can be seen on the screen for it generally contains other things and has only one window which is the most on the left.

So, a hierarchy is established between the name and the other elements of the nominal phrase. Indeed, we consider that the set should contain elements which are not of the type uttered by N, then we will select among the remaining elements to obtain the actual reference.

Trying to translate the interpretation process associated to la fenêtre la plus à gauche *(the window which is the most on the left)* we obtain the following diagram:



Generally the resolution sketch associated to definite description of le N (the N) type is as follows



For this diagram the previous explanations concerning hierarchy must be taken in account.

The problem is now to understand to which extent it is possible to say that a given object is a N or, in terms of associated categories, according to which criteria an object can be predicated by N'. (Class predicate).

In the specific case of a strictly coreferential anaphora it is a lesser problem since we only have to take up the name by which the considered object has been designated. This is what happens in:

> déplace la fenêtre rouge et l'icône bleue. *(shift the red window and the blue icon).*

> agrandis la fenêtre. *(Widen the window)*

Here, the system has only to keep the fact that the referent resulting from the interpretation of la fenêtre rouge *(the red window)* has actually been named by la fenêtre *(the window)* and so, it is the correct applicant for the phrase la fenêtre *(the window)* which is found in the second utterance. This, of course, does not explain why this very object has been initially recognized as fitting the description la fenêtre rouge (the red window) in relation to the other objects on the screen. However, this enables us to follow part of the progress of the discourse and even in certain cases to follow the evolution of the referent as shown below:

> iconifie le texte bleu et la fenêtre verte *(iconofy the blue text and the green window)*
> déplace la fenêtre *(shift the window)*

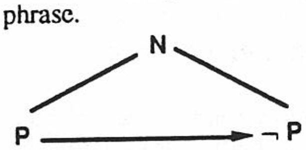
To have a good resolution of the second reference in this example it is important to know that what is now an icon has previously been called a window.

Now, if we consider once again the case for which there has not been a previous reference to establish the association of an object with a peculiar nominal head, we can imagine different solutions. Either the system (or the user) has categorized the objects as their observation went along: this can correspond to the choice of a 'basic term' for each object. As long as the user uses the same term to designate the same object there is no difficulty left to resolve references. Or the system is unable to categorize all the objects of the task and moreover, the user is allowed to use a wide spectrum of names for the objects he considers. Then it is necessary to launch a recognition process for N type objects.This process, somehow or other, has to be based on something prototype like. At the level of temporal phrases we will face once again the necessity to introduce prototypes. For now we will limit ourselves to witness that the use of a prototype for the creation of a referent is all the more capital when we cannot perceive the object directly. (case of the referent associated to temporal phrases).

1.4 Demonstrative nominal phrases

One of the main differences between a definite nominal phrase and a demonstrative nominal phrase is that the last one does not need a set from which it would draw its reference. so, it is impossible to interpret accurately the following set of utterances if by doing so we hope to designate by cette fenêtre (this window) the object previously designated by la fenêtre rouge (the red window).
> (1) déplace la fenêtre rouge et l'icône verte; *(shift the red window and the green icon)*
> (2) iconifie cette fenêtre; *(iconify this window)*

Another difference between the two types of designation is that the demonstrative can also be used to reclassify an element, something a definite cannot do. For instance, Ce matin, j'ai vu Laurent. Ce fameux chanteur... (This morning, I saw Laurent. This famous singer...) is understandable whereas Ce matin, j'ai vu Laurent et Bertrand. Ce fameux chanteur...(This morning, I saw Laurent and Bertrand. This famous singer...) seems awkward. To reclassify the referent with a demonstrative nominal phrase necessarily implies that the N category (in ce N; this N) is not a capital element in search of the considered object. another way to conceive the same phenomenon is to consider that the interpretation process is based on an element which must be salient to be then applied to the constraint expressing that it is an N. In most of the cases this will lead to a referent strictly identical to the one used as a basis for the interpretation. However the two referents can be different as we will see later on. For now we end up with the following diagram translating the constraints mentioned for the interpretation of a demonstrative nominal phrase.



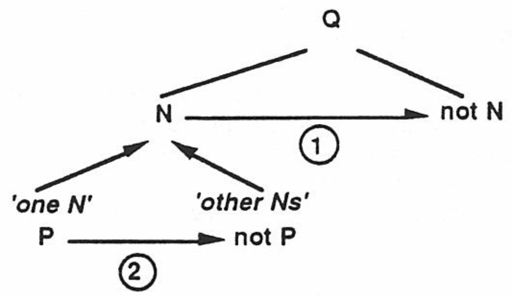
This sketch means that, given a referent possessing properties which are not directly implied by the fact that it is a N (the property of being salient for instance) we add to this the fact that it belongs to the N class. The main reason why we impose that there must be class N members that do not fit the striking properties of the referent comes from the fact that a demonstrative nominal phrase cannot be specific at the N class level as a whole. Therefore, if we have J'ai acheté une Toyota parceque ces voitures sont sûres; *(I've bought a Toyota because these cars are safe)*. Ces voitures *(these cars)* is not refering to all the cars. The referent must show specific properties which allows it to be a particular element in the car class. (Even if this referent has to be generic as it is the case in this example).

The other important point concerning the demonstrative nominal groups is that they can be analysed regardless of the predicate of the sentence in which they belong. Such a phenomenon can be observed in the following exemple: Les italiens exportent cette voiture depuis l'année dernière *(Italians have been exporting this car since last year)* expressed while pointing out a Lamborghini. In this case the referent as such is not only the car pointed out by the gesture, though it must share properties with it. What narrows the range of properties which have to be taken in account is the predicate "être exporté par les italiens depuis l'année dernière" *(be exported by the Italians since next year)*. Let's imagine that the car in question is dirty. If this last property remains among the P-properties used as a basis in the referential computorization (in our diagram) this would mean that it is a significant criterion to isolate the referent in the general class of cars as an object "exportable par les italiens" *(which can be exported by the Italians)*. As it is generally understood that italians do not first and foremost export dirty cars, it seems clear that this choice is incompatible with the uttered predicate.

The interpretation of a demonstrative nominal phrase takes place in this way: given a salient object (because of it being mentionned in an immediate previous utterance or by a pointing gesture) we assign it to the N class (which leads us to map it with the prototypic properties of the class). Then we eliminate a certain number of properties which do not match with the predicate applied to the temporal referent. The final result of this computed set is represented by the set of initial properties which have not been eliminated. Otherwise, there would have been a generalization effect corresponding to a specific utterance. Besides it is necessary that a number of those initial properties are kept so the utterance remains understandable (cf: "ce parfum est ouvert à la page 4"; *this perfume is open on page 4*). Then, in order to justify the re-categorization in the N class it is essential that the predicate does not suppress all the properties issued by the prototype. Such a principle allows to justify the interpretation of utterances such as: Ce jour sera célébré tous les ans. *(this day will be celebrated each year)*

1.5 Indefinite nominal phrases

We can present the computed set diagram associated to the indefinite nominal phrases more rapidly. This diagram rounds off what we have presented for the definite and the demonstrative:

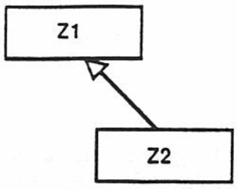


Here, the main idea is to represent the fact that when we express un N *(a N)* we identify a peculiar referent inside the N class knowing that these peculiarities, as opposed to what happens for ce N *(this N)*, shall not be previous to the occurence of the definite expression. On the other hand they are confirmed or precised by the predicate. Thus, if we state: un triangle a trois côtés *(a triangle has got three sides)* the predicate brings no particular porperty (in relation to the prototype triangle for instance) the utterance has then a generic value. On the other hand, in the case of un chat *(a cat)* in un chat mangeait *(a cat was eating)*, the P-properties are confirmed: the predicate cannot be applied to all the elements of the class (especially because of the temporal mark). The utterance has then a specific value. The referent, as in the demonstrative case, is built on the basis of a prototypic description available for instance at the lexicon level.

2. Some elements for the represention of time

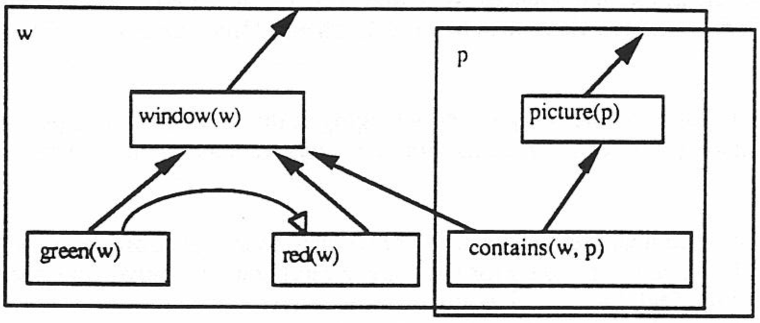
As we pointed out in the introduction we are in need of a temporal representation associated to the objects of the task. generally speaking any interpretation process (of a text or of an utterance in a dialogue) has to insert itself in a particular temporal frame. At our level and considering the type of information carried by language, an accurate temporal representation in the frame of automatic understanding should essentially possess the properties of localization of information and should be able to express the constraints bound to relative time. Moreover such constraints do not have to be very precise. This is why we will limit our study to the introduction of two relationships between temporal elements: the precedence and the inclusion. These relationships beyond their strict temporal interpretation can be seen as elements of articulation for the underlying logical reasoning. In this way stating the precedence of two zones, Z1 and Z2 as in the sketch below is like uttering the incompatibility of the informations carried by these two zones. (ex: la fenêtre a été verte puis rouge; the window has been green then red).

As well, an inclusion between two zones Z1 and Z2 as above allows to show the logical dependance of the informations contained in one in relation to the informations contained in the other.



To put it differently, all that is described at the level of Z2 is limited in time by what is described at the level of Z1[6] . On the contrary all the informations described at the level of Z1 are necesserally true for Z2 and consequently must be inkeeping with what is described at the level of Z2. Then, we can point out that between two data zones only one of the mentioned relationship can be established even if in some cases neither is valid. (case of a temporal split between two zones).

Among the set of temporal zones it seems useful to isolate a special sub-set we call universe of object (Romary 1991). These zones represent the temporal development associated to objects perceived or mentionned in a discourse. In practice identifiers are associated to these universes of objects, they will be used as a variable to describe the known properties of an object. Then, we will have this type of representation:



This diagram represents the "story" of window which has been green and of which we know by now that it is red. Besides, the window contains an image, though we don't know how to synchronize this information with the one of the colour. However if we have been able to describe the fact that a window can only have one colour at the same time, we can state that the two zones associated to the predicate 'red(w)' and 'green(w)' are in the position of precedence.

the type of reasoning which has been carried here hinges upon a tacit use of the present tense. We consider the most recent - and compatible - informations we possess concerning an object to be valid at the present moment. Though this may seem at face value awkward, such an hypothesis is very often used in the launching of a task oriented dialogue.

According to this representation, the recognition of a prototype on an object equates to detect that no new information has been added while applying the prototype on the object.

3. Different temporal phrases.

When we ponder over temporal phrases such as le matin *(the morning)*; cette semaine *(this week)*, or un jour *(a day)* [7] we quickly notice that they can be clearly divided into two distinct classes. On the one hand we can isolate what we can call 'time units' in which we find terms such as mois (month), jour (day) (in one of its uses), heure (hour), minute (minute), seconde (second). On the other hand we find terms of period which fit ordered series as for instance, matin (morning) or novembre (November). Considering the nature of other temporal elements which co-exist in a wider interval with the given unit, these terms can respectively be qualified as homogeneous and heterogeneous units. In this way, a minute is 'surrounded' by other minutes in an

[6] The mathematic concept of opened or closed interval having of course no meaning in the context of a linguistic phrase or more generally of human reasonning.

[7] There is a very large spectrum of temporal adverbials for which many global analyses have been made (Bras 1992). Our aim is tofocus on the details of the functionning of a reduced number of phrases.

hour. On the other hand, a morning, in a day will be an alternative to an afternoon or an evening according to the context.

If we admit the principle of a semantic representation - for instance such as Rastier (1987 and 1989) proposes it - which would give us the means to gather the lexical items according to their properties of homogeneity and in conformity with the classification which has been introduced, we still need to establish the constraints which will enable us to change this representation into a prototype.

In the case of homogeneous units, what opposes one of them (for instance an hour) to the other (a minute or a day) can be represented at the level of a prototype which would be associated to it thanks to a relationship of temporal inclusion. A minute is included into an hour, the hour can be defined as included into a day, and so on.

In the case of heterogeneous units, the semantic opposition between a morning and an afternoon will be expressed, at the level of a prototype, by a relationship of temporal precedence. A morning precedes an afternoon, in the same way janvier *(January)* precedes fevrier *(February)* etc...

Considered the sequence of the different utterances we notice that Ce dimanche-là (...). Le matin *(That sunday (....). The morning)* is acceptable, whereas Ce dimanche-là (...). L'heure *(That sunday (...). The hour)* is not.

so, if we wish to use a phrase of le N (the N) type - N belonging to the set of the homogeneous units - it is necessary to give further precision (in order to break the homogeneity) such as le jour suivant *(the next day).*

This seems clear and would be compatible with what has previously been said concerning the definite nominal groups. This is not relevant for l'heure *(the hour)* for there are several hours in a given day such as the one introduced in Ce dimanche-là *(that sunday).*

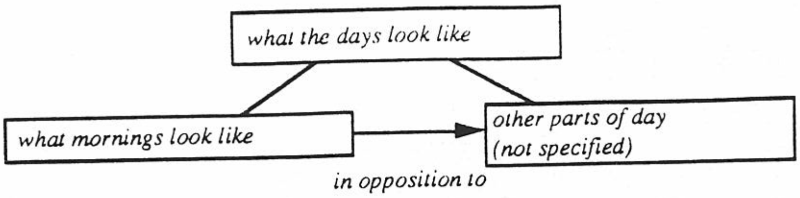
However, some examples seem more difficult to treat in the frame of our hypotheses. Le matin *(the morning)*, out of a context cannot refer to the current day. In the same way, ce matin *(this morning)* expressed in the afternoon refers to the morning of the day in which the afternoon is included (i.e the current day).

If we keep the interpretation we proposed for definite and demonstrative nominal groups, we must consider in the first case that the current day is not accessible and in the second case that the morning of the curent day is salient in the discourse or the situation. We would have the following paradoxal situation: the morning of the current day would be salient whereas the current day would not. This seems difficult to admit and it is then necessary to refine the mechanism introduced in order to understand the grounds of the phenomenon.

3.1 Definite temporal phrases

We have shown the way le N *(the N)* works as a selection, inside of a set, of an element which can be qualified as - or called - N. However the problem of generic phrases has been very little treated, as well as the problem of phrases which refer to objects which do not belong to the perceptual space shared by two speakers. In this case it may happen there is no set in which we can find a N that fits. Though if we must carry on the analysis on this ground we must imagine there is one in any case and precise the requirements for its creation. In such a context the considered set is necessarily built on the basis of semantic datas. So, to identify le matin we not only need to possess a prototype associated to matin but also a representation which would allow us to oppose matin to other lexical items which might challenge it. In the introduction we pointed out that the study of temporal phrases may ease the understanding of the reference phenomenon for they seldom were under the influence of a predicate.

At this stage we notice that in addition to a prototypic representation of the set in which it is possible to extract Ns, it could be possible for the predicate in an utterance to guide or to restrict the choice of this set. The development of this idea would lead us far from the field of this article. Taking over the analysis of le matin we end with a reference resolution which may be expressed by the following diagram.



The computed set of the referent is then kin to a matching between the abstract set representing the day and a compatible element in the discourse memory recorded at this time, in order to display the very morning it is about. This mechanism explains sets of expressions such as ce dimanche-là(...) *(that sunday)* Le matin *(the morning)* ... The abstract day in which an abstract morning appears filters the day associated to ce dimanche-là *(that sunday)* (without giving new informations) in order to display a morning which easily opposes to the other parts of the day: Le matin, je me lève *(In the morning I get up)*. In this example (supposed with no previous linguistic context) we cannot resolve the contextual referential phrase since nothing at all matches our abstract day. Consequently, our abstract day remains abstract and the phrase is then interpreted as generic.

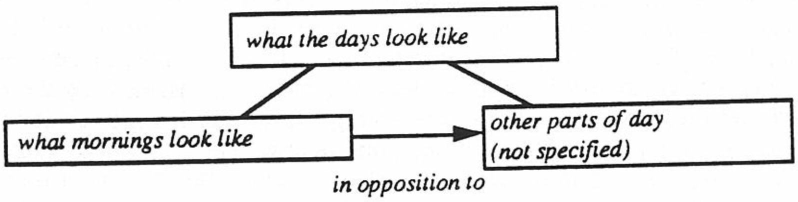
Another difficulty appears in the case of Le matin, je me casse une jambe (In the morning, I break my leg) if we stick to a generic interpretation we are led to a contradiction between the utterance and the probability to break a leg every morning.

3.2 Demonstrative temporal phrases

3.2.1 Generalities

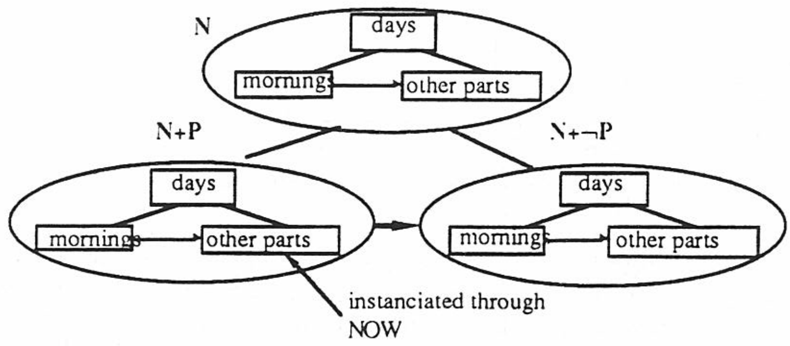
The second problem we shall ponder over now is the interpretation of a phrase such as ce matin *(this morning)* expressed at different moments of the day and not necessarily during the actual period associated to this phrase. The explaination we gave - which fits the constraints imposed by man-machine dialogue - was based on the notion that the referent was being salient when associated to the demonstrative phrase. However, in most of the contexts there is no explicit reference made to a peculiar morning which *a fortiori* forbids any saliency to sustain the analysis of ce matin. Though, it is possible to consider that at any moment the current instant (we can call NOW) is in a salient position in a dialogue . In the case of a narration a similar property can be observed for the moment of attention in the temporal unfolding. From now on the demonstrative phrase can be seen as a re-categorization of NOW under the shape of a morning. The main idea here is to consider that NOW supplies the P-properties necessary to the intanciation of the prototype associated to the notion of morning.

The prototype is of course the same as the one presented in the previous section:



In which the relationship between the morning and the other parts of the day is an abstraction of the temporal relationship of precedence we talked about in part 2.

Given this protoype describing what a morning is like, a demonstrative nominal phrase will be able to refer to an object of the universe which distinguishes itself from the nominal phrase according to P-proprieties (peculiar). In the present case, the only properties we can imagine (in the absence of a predicate) are those linked to the present instant. This allows us to draw the following diagram:



The important thing pointed out by this diagram is the fact that instanciating a sub-part of the prototype is enough to instanciate it as a whole. The final referent is of course on the sub part of the instanciated prototype which fits the N description to be found in the referential phrase. What distinguishes it from other Ns comes from another part of the prototype.

Now we can come back to phrases such as ce jour sera célébré tous les ans *(this day will be celebrated each year)*. The computed set we view is always launched in a way similar to those presented up to here. Whether the prototype associated to jour *(day)* contains or not informations about weeks is not important here. But each time a day prototype is instanciated with an anchoring on NOW the predicate must be applied on it. Moreover, applying a predicate can lead to the withdrawal of a certain amount of properties among those of the set, gathering those of the prototype of Ns and the P-properties which have allowed to instanciate it. However we are submitted to two constraints

On the one hand, at least one P-property must remain in order to preserve the specificity of the instaciation of the N which has been chosen, and consequently forbids any genericity at the level of all Ns.

On the other hand there must be enough properties left for the object to be qualified as a N. The aim of ce N (this N) being to situate a referent in the N set.

The second constraint indicates that it is impossible to suppress properties among those which characterize, for instance, a day, to the point that it could as well be an hour or a month in the same context. In this way, in Ce jour sera célébré (this day will be celebrated...) it is not enough to keep what is celebrated (a victory, a birth etc...) we also have to keep the fact that the event happened at a day's scale.

3.2.2 Habits contexts

The analysis we have carried previously shows the necessity to stick to a temporal zone designated by a demonstrative phrase on the basis of an abstract prototype which draws its possible boundaries. This point is particularly interesting in the automatic treatment of demonstratives since the referential analysis becomes similar to a kind of pattern matching. To be able to extend the process to other types of demonstrative expression other axes of representation would still have to be defined (spatial for instance) on the basis of relationships similar to inclusion and precedence which are used to represent time. It is not our point here, futhermore other problems remain concerning the treatment of temporal phrases. One of these problems is the status which is to be given to the prototypes used in the referential sketches associated to demonstrative. The way they have been presented, it seems that for any given N, the associated abstract representation has unchanging characteristics so that it can be directly extracted from a computorized lexicon defined beforehand. However, observations of the occurence of demonstrative phrases in the narative context seem to indicate a phenomenon of particularization of the abstract sketches used for the analysis of temporal demonstrative phrases. in such a frame these phrases most often appear under the shape of ce N-là (That N) in order to raise the ambiguity related to the double temporal anchoring which can occur on the instant of the narration or on the focus of the story[8].

If we rapidly scan the whole of a narration in which phrases such as ce N-là occur, we notice that they mostly appear in what we can call habits contexts, that is to say general descriptions of a behaviour which can

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[8] The analysis in terms of inclusion/exclusion (Debruyn 1992) seems too mathematic to reflect a phenomenon which belongs more to the discourse than to associated temporal onthology.

be more specifically instanciated in the field of demonstrative phrases. As an example, we can consider two short extracts by Maurice Leblanc in which temporal situations are introduced.

Le collier de la reine	*The queen's necklace*
Deux ou trois fois par an, à l'occasion de solemnités importantes...	Twice or thrice a year, on solemn occasions
[...]	(...)
[...], l'après midi du jour où sa femme voulait s'en parer...	(...) The afternoon of the day his wife wanted to adorn herself with it ...
Ce **soir-là**, à la reception du Palais de Castille,...	The same evening, at the reception at the Palais de Castille.

Le piège infernal	*The diabolical trap*
Les époux Dugrival et leur neveu, [...], presque chaque jour...	The Dugrival couple and their nephew (...) almost everyday (...)
En général, le ménage restait assis...	Generally, the couple remained seating...
La chance, ce jour-là, ...	By luck, on that day.

In both cases, the demonstrative phrases designates a peculiar evening or day in the context of a serie of usual behaviours. It is then impossible to state that in this context, the abstract evening or day which is instanciated is the more general prototype we can get at the lexical level. On the other hand in none of the cases encountered (in about ten novels or short stories by the same author) indicates a real anaphorical take up by the ce N-là phrase. Each time the aim is to indicate that the period displayed possesses something peculiar the rest of the narration is going to complete. This behaviour seems then to ratify in terms of oppostion the analysis we have presented for temporal demonstrative.

We can then point out that the behaviour observed for demonstrative phrases may occur for some indefinite phrases which of course can introduce new temporal periods. Such a parallel justifies the similarity between the schemes associated to ce N (this N) and un N (a N) the main difference between them, that is to say the necessity of a pre-existing opposition for ce N (this N), being erased by ty the beginning of narration effect[9] .

The following example illustrates such a parallel:

Arsène Lupin en prison	*Arsène Lupin in jail*
Chaque jour, au coucher du soleil, ...	Everyday, at sunset...
Or, **un vendredi de septembre**, ...	When, one friday of Semptember...

It is clear that at this stage, in the field of an automatic analysis of demonstrative phrases,we are not able to define the computed set which would allow us to progressively define the abstract representations associated to the nominal heads according to peculiar contexts. The above observations, which should be completed by more accurate linguistic analyses, give us hints in order to precise the nature of the models we use.

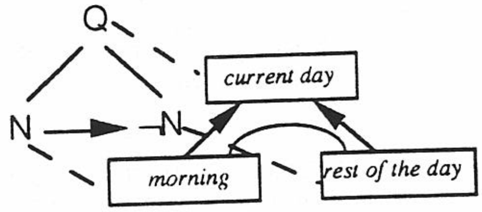
4. Conclusion

In this article we have tried to apply a certain amount of hypotheses concerning the processes of referential interpretations to the specific cases of temporal phrases. We have then been led to consider a double movement. On the one hand, le N (the N) draws its reference under the shape of a micro-period originated from a wider temporal period (that is to say a temporal inclusion). On the other hand, ce N (this N) is based on a shorter period (often as a focus point in the discourse) and ends up in a macro-period.

[9] This effect occurs when defined descriptions appear without any previous context.

working on temporal phrases has obliged us to refine the nature of general oppositions which have been introduced in our sketches. Since temporal phrases do not refer to material objects (in opposition to the exemples we were used to work with) it seemed necessary to introduce prototypes.

More generally the study of temporal phrases has raised the problem of the articulation of referential computed sets (opposition sketches inside of a set, of a situation) and of an ontology - in our case of the temporal zones- as the basis of a system of reasoning on this world. The first one is by nature linked to language and to its mechanisms whereas the second one is related to the knowledge of the world. At the temporal level, we notice that none of these levels of representation is superfluous. Consequently in the field of the automatic understanding of a reference we must have two types of diagrams. For le matin *(the morning)* the referential access of le N *(the N)* type finds its counterpart in a temporal sub-structure such as shown on the following diagram:



The referential part allows the discourse to keep a certain continuity (anaphorical take up etc) whereas the cognitive part is used as an angle stone for potential reasonings on time. So, the referential diagrams give a more abstract view of the represented world and express the fact that language gives more of a point of view on knowledge than a real description of them as opposed to what a too vericonditional semantic would like us to believe.

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Another look at the temporal system of English

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The dynamism of a narrative arises in part from information about the events and states presented in it, including their temporal location and aspectual value. In this paper I will present an account of the information conveyed by the temporal expressions of English. Assuming the framework of Discourse Representation Theory, I will state temporal features and computations for the construction algorithm to deal with temporal information. The construction algorithm takes as input the surface structure of sentences, and produces a dynamic Discourse Representation Structure (DRS).[1] The information given by linguistic forms is augmented by pragmatics: pragmatic inference mediates between the text and the mental representation of its content.

I will follow the general approach of Hans Reichenbach. Reichenbach posited a system with three times to account for the temporal information conveyed by sentences. Speech Time is the central anchor of the system; Reference Time relates to Speech Time, and Event Time relates to Reference Time (I will use the term Situation Time rather than Event Time, to include events and states). Some changes and additions are necessary.

There are cases where Reference Time relates to a time other than Speech Time. In embedded sentences and in discourse contexts, Reference Time orients to a time established in the context. Moreover, in continuing discourse the Reichenbach approach is relevant only for the first sentence. Later sentences relate directly to the time set by the first sentence, and do not involve three times. The system must be augmented by a pragmatic principle of advancement, as is well-known. I point out in §3 that we need a different pragmatic principle for verbs of communication.

§1 gives a feature analysis of the temporal expressions of English; §2 discusses the interpretation of syntactically independent sentences; §3 discusses verbs of communication and statives with complement clauses.

§1. The temporal expressions of English

I will deal with the present tense, the past tense, the future *will*, auxiliary *have*, and Locating adverbials.[2] This analysis assigns features to temporal expressions, and uses rules to compute the temporal information in a sentence. Rules are required because the interpretation of a given expression varies according to the other temporal expressions in the sentence and the context.

I propose three types of features for temporal expressions: Relational, Orientation, and Role. The relational values are Anterior, Simultaneous, Posterior.

The Relational value of an expression is indicated lexically. For instance, the present tense and the adverb *now* have the value of Simultaneity, the past tense, auxiliary *have*, and the adverb *yesterday* have the value of Anteriority, etc.

The Orientation feature indicates how flexibly an expression orients to times established in a discourse. The tenses, both past and present, orient to a Present or Future time (I capitalize references to times, and indicate tenses with lower case). To see this, we examine their interpretations in different contexts. In independent sentences, both tenses orient to Speech Time (SpT) and indicate an RT related to SpT by the relational value of the tense: the present tense indicates a time simultaneous to SpT, the past tense indicates a time anterior to it.

1 a Jane lives in Istanbul.
b Mark bought a rug.

Other possibilities arise in complement clauses. We ask whether the tense of an embedded complement clauses orients to the time of the main clause, or to another time. If the main clause has a nonpast time both tenses orient to that time. 2-3 illustrate.

2 a Mary thinks that she is a candidate.
b Bill says that he won the election.

3 a Bill will say that he won the election.
b Mary will announce that she is a candidate.

The main clauses establish Present and Future times in 2 and 3, and the complements indicate times anterior and simultaneous to those times. In contrast, neither of the tenses orients to a Past time. Consider how the complements are interpreted in 4.

4 a Mary said that she is a candidate.
b Mary said that she was a candidate.

In 4a, the main clause time is Past and the complement clause orients to SpT. In 4b, the complement has the same time as the main clause, not a time anterior to it. I return to these cases in §3 below. Taken together, examples 1-4 show that both tenses have an Orientation value of Nonpast.

We need two additional Orientation features to account for the full range of temporal expressions. Most adverbials, and *have* and *will*, are flexible in orientation. But there is also a category of deictic adverbials which orients only to SpT, which requires a different feature. The Orientation features are thus Nonpast, Flexible, SpT.[3]

Tmporal expressions may play different systematic roles in sentence interpretation: tense and adverbials may contribute to RT or SitT, as the examples illustrate:

5 a Mary called on Tuesday.
b Mary called yesterday. She was excited.
c Last week, Keith comes up to me all of a sudden and laughs.
d Bill said that Keith was leaving in 3 days

In 5a, the tense indicates a Reference Time (RT); in the second sentence of 5b, the tense continues the RT which is previously established. In 5c the adverbial specifies RT, whereas in the complement of 5d the adverbial specifies Situation Time (SitT). We need rules to compute these interpretations.

Auxiliary *have* has the same flexibility, with the relational value of anteriority. It may contribute to either RT or SitT: thus *have* indicates SitT in 6, and RT in 7.

6 auxiliary *have*: SitT < RT
a Mary has arrived

b Mary had already arrived
c Mary will have arrived

7 auxiliary *have*: $RT_2 < RT_1$
Last Sunday John left the county. On Friday he had closed his bank account, and had rented his house; at his office, he had emptied all the drawers and shelves; then he had told his staff to take a holiday, and had made his final arrangements.

In fragment 7, the first instance of auxiliary *have* sets up a secondary RT; the subsequent sentences with *have* carry on from there. This dual use of *have* is well-known.

Now consider future *will*, a modal with the relational value of posteriority. Unlike the other temporal expressions of English, *will* has only one role: it always contributes to RT. This analysis arises when we consider the times involved in clauses with *will*. They minimally require two times: an anchor and a future time indicated by *will*. But clauses with *will* can always be more complex with auxiliary *have*, as 8a-c illustrate.

8 a Mary will have already arrived.
b Mary says that in 3 days she will have finished her project.
c Mary said last Sunday that in 3 days she would have finished her project.

These clauses involve three different times: OT, RT > OT; SitT < RT the latter indicated by auxiliary h*ave*. I assume that *would* is a past-tense version of *will,* following Chomsky's Syntactic Structures analysis. Note that 8c involves four times altogether, since the main clause sets a Past OT for the complement (cf Ogihara 1989).[4] We can account for sentences with *will* by specifying a Role Feature limiting its role to RT. The features I proposed are summarized in 9.

9 Features for Temporal Expressions in English

	Relational			Orientation			Role
	<	=	>	Flex	SpT	Nonp	
present tense		+				+	
past tense	+					+	
aux *have*	+			+			
modal*will*			+	+			RT
Locating adv							
at - o'clock		+		+			
-- ago	+			+			
yesterday	+				+		

The rules of the construction algorithm automatically have access to these features: they are listed in the lexical entries for temporal expressions.

§2. Rules for independent sentences

There are striking differences in the temporal interpretation of sentences, depending on the context in which they appear. Independent sentences, and the first sentences of a discourse, are oriented to SpT. In a continuing discourse, however, subsequent sentences are related to preceding times and sentences rather than to SpT.

In the framework of DR theory, temporal interpretation arises with temporal entities and conditions which characterize them. The entities are automatically introduced for each clause in the DRS: there are three times, t_1, t_2, and t_3, which correspond to SpT, RT, and SitT respectively - following Kamp & Rohrer 1989. Rules of the construction algorithm interpret temporal information as conditions on temporal entities.

The rules are stated to account for sentences with both tense and adverbials. Some combinations establish RT, others do not. I consider first combinations of tense and adverbial that establish RT; in these examples RT=SitT. 10 illustrates:

10	a	Jane left 3 days ago	(tense <, adverb <)	RT α SpT, RT=Adv
	b	We are ready now	(tense =, adverb =)	"
	c	Michael leaves tomorrow	(tense =, adverb >)	RT β SpT, RT=Adv
	d	Last week, this guy says...	(tense =, adverb <)	"
	e	Sam will arrive tomorrow	(tense =, *will*, adverb >)	RT > SpT, RT=Adv

We can account for 10a-b with a rule using the α notation. Thus rule 11 applies when tense and adverbial have the same relational value, and provides that value for the relation of RT to SpT. For 10c-d we use a β notation to ensure that tense and adverb have different relational values (rule 12). In these cases the adverbial specifies RT. 10e, with future *will*, 10e, requires a rule mentioning *will* and present tense (rule 13).

11 If [X $_{tns}[\alpha]$ + Y + ($_{adv}[\alpha]$)] then $t_2\ \alpha\ t_1$, t_2=Adv, $t_3=t_2$.

12 If [X $_{tns}[=]$ + Y + ($_{adv}[\beta]$)] then $t_2\ \beta\ t_1$, t_2=Adv, $t_3=t_2$.

13 If $_S[X\ _{tns}[=]\ +_{will}[\ >, RT]$ ([LAdv]) then $t_2 > t_1$, t_2=Adv, t_3=t_2.

Adverbials are always optional; sentences without them have the value indicated by tense and other optional temporal forms. t_1= Speech Time, in the general, default case. $t_2 = t_3$ (RT=SitT) except with auxiliary *have*, dependent adverbials, or complement clauses that take their RT from the main clause (see below for the third case).

To give a clear picture of how the rules actually translate into a DRS, I present in 14 a DRS for the temporal interpretation of 10a. The DRS includes aspectual entities: a situation entity, a temporal interval I, and designated times. Like the temporal location entities, they are introduced automatically with every clause; see Smith 1991, chapter 7.

14 temporal DRS for *Jane left 3 days ago*

	t_1 t_2 t_3 x y I e t_i
1.	e = [X leave]
2.	e = {Achievement}
3.	e at I
4.	{Viewpoint$_I$ (e) = Perfective}
5.	{t_i} = I
6.	t_i = *I* (e)
7.	I at t_3
8.	$t_3 = t_2$
9.	t_2 = 3 days ago
10.	$t_2 < t_1$
11.	t_1 = SpT
12.	x = Jane

This DRS is produced by Rule 11.

There are also combinations of tense and adverbials which do not establish RT. Without context, these sentences cannot be fully interpreted: they are temporally incomplete. 15 illustrates.

15 a Jane was leaving in 3 days (tense <, adverb >)
b Michael was ready now (tense <, adverb =)
c Sam would leave in 3 days (tense past, *will*, adverb >)

We know from 15a that Jane planned to leave 3 days from some past time, but can't compute the actual time; nor can we compute the time of *now* in 15b. In 15c we recognize an RT, since *will* appears, but cannot interpret the sentence because the orientation time is not specified. Sentences like this generally appear in a context which specifies the missing time. They are natural as complement clauses, or as independent sentences in a continuing discourse. Rules 16-17 interpret them as fully as possible in the absence of other information. The past tense indicates that they involve a time prior to SpT.

16 If $[X\ _{tns}[<]\ Y\ (_{adv}[\beta])]$ then $t_2 < t_1$, t_2=?, t_3=Adv.
RT < SpT, RT= ...; SitT β RT

17 If $_{Sn}[\ X\ _{Tns}[<]\ \ _{will}[\ >, RT]\ \ _{Y}\ ([LAdv])$ then $t_2 <$?, t_2=RT, t_3=Adv.
OT=...RT_{n-1}, RT_n > OT, Adv=RT, SitT=RT

Rule 16 uses the β notation to indicate different relational values. Rule 17 requires an Orientation Time (OT) which differs from SpT, the default value of OT. Complement clauses like this are discussed in §3.

Returning to temporally complete sentences, note that the rules correctly interpret the first sentence of a discourse. 18 illustrates:

18 Three weeks after Granny Blakeslee died, Grandpa came to our house for his early morning snort of whiskey. (Burns, *Cold Sassy Tree*)

This sentence, which opens a novel, sets the stage for subsequent sentences. It can be interpreted by Rule 11: the temporal clause plays the role of a Locating adverbial, which specifies the past time of the main clause. I now turn to sentences in discourse. They have similar temporal expressions, but are interpreted quite differently.

2.2. Sentences in continuing discourse

In continuing discourse, temporal interpretation does not follow the pattern presented above. Consider 19, a fragment from the same novel as 18.

19 The sun was barely getting light and the birds just beginning to wake up and sing when I tiptoed downstairs in my Sunday suit and my new linen duster. Queenie hadn't even gotten there yet. After washing down a cold biscuit with some sweetmilk, I put on my driving cap and goggles and had just sneaked out the back door when Papa leaned out of his bedroom window upstairs.

The first sentence sets the time for subsequent interpretation. The other sentences indicate situations that are related temporally to the time of the first. In this fragment the situations follow each other successively; this is not always the case, of course.

We understand the other sentences in terms of successive RTs which depend on two kinds of information: the adverbials, and pragmatic advancement. We must provide that an RT advances after a closed event by the time involved in the event (Cf proposals by Kamp, Partee, and others.) I assume that closed events advance a discourse, and that states and open events do not, at least in unmarked cases.[5] The times of the situations in 20 are indicated schematically with a time line: > indicates pragmatic advancement.

20 RT_1...........>..............RT_2...........>.RT_3........>.RT_4........>.RT_5.........
S_{1a}......S_{1b}......S_2.........S_{3a}.............S_{3b}.........S_{3c}.............S_{3d}........
when hadn't after had just when
sun tiptoed gotten wash down put on sneaked Papa leaned

The first clauses present open events and do not affect RT; RT_1 advances at the third clause of S_1 by the time for sneaking downstairs; RT_2 advances at the second clause of S_2 by the time for washing down biscuit and milk; etc. Thus, in order to accurately model the course of events depicted in 20, we allow for the time involved in the occurrence of the closed events. This amount of time appropriate for advancement is a pragmatic matter.

The adverbials in fragment 19 are unusually informative, yet the pragmatic advancements are still needed. This example shows that the principle of advancement is independent of how much adverbial information appears in a discourse.

The analysis does not involve three times that the system makes available for independent sentences. Our understanding of the past tenses here is similar to the Sequence of Tense pattern; see §3 below. Note that the sentences all have the same tense. If they did not, we would not interpret them as a continuing discourse temporally.

Now consider another narrative fragment. The sentences have the same tense and there is only one adverbial, *then* in the third clause of the second sentence.

21 I slipped outside into a shock of cool air and ran down the pier to a cluster

> of small boat rocking lazily to and fro in the water. I unfastened the rope to one, paddled out toward the "Republic," then hauled myself hand over hand up a rope ladder to the topgallant bulwark, and over onto a broad empty deck. (Charles Johnson, *Middle Passage*)

We have little difficulty constructing the order of events in this fragment: they too advance in succession. Again, the dynamic narrative does not depend on temporal expressions: RT advances according to the pragmatics of the discourse. Of course, narratives do not always present situations successively. I assume that the default order is succession, however.

I suggest that the function of tense in discourse is to indicate continuity. If there are adverbials, they contribute to the calculation of the dynamics of discourse. RT is advanced or retracted, according to the adverbials and to pragmatics. This function contrasts with the type of tense interpretation discussed earlier, in which tense indicates the relation betwen Speech Time (or another Orientation Time) and Reference Time. 22 indicates the interpretation of non-first sentences. S_2 has the same tense as a preceding sentence S_1.

22 a If S_1:$[_{tns}[\alpha]]$, RT_1; S_2: $[_{tns}[\alpha]\ ]]$ then $[\ RT_2 > RT_1]$

b If S_1:$[_{tns}[\alpha]]$, RT_1; S_2: $[_{tns}[\alpha]\ _{LAdv}[Rel]\ ]]$ then $[RT_2\ Rel > RT_1]$

The advancement required is indicated in both rules by >. 22a assumes the default order of succession; 22b provides that the adverb indicates the relation between RT_1 and RT_2.

The rules of 22 are not systematically complete, because they give interpretations only for RT. No values are assigned to the other times. But there is no need for three times in these cases: RT relates to a previous RT, not to SpT or to another OT. For a uniform system, we can simply provide that in rules like these, OT=RT. In the DRS, then, t_1 is automatically the same as t_2. For sentences with *have* or temporally incomplete sentences, we will compute a SitT that differs from RT ; otherwise, $t_3 = t_2$.

§ 3. Embedded complement clauses

There are several patterns of interpretation for finite embedded clause complements.[6] In the first, the orientation pattern, a past tense is embedded under a main clause with a nonpast time. The past tense has its consistent relational interpretation: it indicates a time anterior to that of the main clause. Thus the main clause establishes the Orientation Time for the complement. 23 illustrates; c shows that independent clauses do not allow the orientation interpretation.

23 a Mary will announce at midnight that she resigned an hour earlier.
b Mary thinks that Bill resigned.
c ?*Mary will announce it at midnight. She resigned an hour earlier.

24 gives a rule for interpreting such complement sentences, which orient to a time of the main clause. SitT in the main clause specifies OT for the embedded clause.[7]

24 If $_{s0}[_{Tns}[=]\ _{S1}[\ _{Tns}[<]\ Y\ _{LAdv}[<]]]$ then $_{s1}\ [t_1 < t_3,\ t_2 = Adv,\ t_3 = t_2]$

$s1\colon RT_1 < SitT_0,\ RT_1 = Adv,\ SitT_1 = RT_1$

The rule is stated so as to require syntactic dependency.

The second pattern has a past tense embedded under a past tense. In this context the past tense indicates continuity with the time of the main clause, and not a time anterior to it. This is the well-known phenomenon of Sequence of Tense.

25 a The company admitted yesterday that it cut its work force recently.
b Mr Mosbacher said that he made his comment only in response to a question directed to him. (New York Times)
c Marge knew that Edward won the race.
d Sue believed that Edward was sick.

The complement clauses of 25 indicate a time roughly simultaneous with that of the main clause.[8] They can be analyzed as sharing the time of the main clause. Thus the tense in the complement mirrors the tense of the main clause. In this way the consistent relational value of the past is maintained, while allowing for the fact that the complement tense does not introduce a new time (Cf Smith 1978).

I would like to focus here on the relations between the situations of main and complement clauses. We might expect that an advancement principle would be needed for the complement clause, as in the independent sentences discussed above. But such principle is not appropriate: these cases are quite different. Rather than advancing the narrative, the complements of 25 present situations that either overlap or precede those of the main clause.

The key factor is the type of verb that appears in the main clause. The verbs in 25 are verbs of communication (25a,b) or stative verbs (25c, d). With states the main and complement clause situations overlap, since no endpoints are involved; states do not include their own endpoints (Smith 1991).

In contrast, communicative verbs always indicate a previous event or overlapping open situation. The reason lies in an implicit convention of communication. We take communication, and reports of it, to be instantaneous; therefore any closed events reported by verbs of communication must precede the communication itself. The convention holds even if the events reported is instantaneous; for discussion, see Smith 1991, Kamp & Rohrer 1989. We need, then, a different principle for verbs of communication: their complements have RTs which are anterior or overlapping to the main clause time.

This principle explains some variation in English. For some speakers auxiliary *have* is optional in sentences like 25 a-b, which have verbs of communication. When *have* appears, it doesn't change the interpretation, because the prior interpretation arises anyway for such cases. But if the embedded clause is stative, the presence of*have* changes the interpretation. 26 has non-stative embedded clauses, 27 has statives.

26 a Bill said that John pushed him.
b Bill said that John had pushed him.

27 a Bill admitted that he was sick.
a Bill admitted that he had been sick.

In 27a, the time of main clause and complement are the same; in 27b they are different.

Returning to verbs of communication, we need a rule to retract the complement RT to a time immediately before the communication of the main clause. Rule 28 does this: both clauses have the same tense, and a verb of communication appears in S_1.

28 If $_{S1}[\ _{v}[\text{comm}]\ _{tense}[\alpha]\ _{S2}[[\ _{tense}[\alpha]\ ]$ then $[\ RT_1 < RT_2]$

The embedded clause may have an adverbial which specifies a time prior or subsequent to the main clause, as in 29:

29 a Mary revealed that John was arriving in 3 days.[9]
b Sam announced that he married Ellen 3 days ago.
c Jane realized that she was tired now.

The interpretive rule for such sentences interprets the adverbial in the complement as specifying a complement SitT that may differ from RT, according to its relational value.

30 If $_{S1}\ _{v}[\text{comm}]\ _{\text{tense}}[\alpha]\ \ _{S2}[[\ _{\text{tense}}[\alpha]\ _{\text{LocA}}[\text{Rel}]$ then $[RT_2 \text{ Rel } SitT_1]$

Again, in these rules we vacuously provide that $t_1=t_2$.

The third pattern of complement clauses is exemplified by 33, in which a present tense complement is embedded under a past tense complement.

31 Bush understood that the Reagan right is the most important Republican constituency in the election. (Dionne, Why Americans Hate Politics)

Here the complement sentence is not related temporally to the main clause but to SpT: it involves the speaker. Sentences of this type are quite complex semantically, involving an intensional factor in the main clause.[10]

Relative clauses are like complements in that they relate either to SpT or to the main clause time, depending on the tense values of both.

Summarizing, I have presented a systematic account of the temporal expressions of English within the framework of DR theory. I have shown that different treatments are needed for independent and first sentences, and for non-first sentences of continuing discourse. I have also shown that verbs of communication with complement clauses require a special principle of interpretation which retracts RT in the complement.

Footnotes

1. The analysis presented here is substantially different from that of Smith 1978, which also deals with the temporal system of English. For space reasons I do not deal here with temporal clauses or relative clauses.

2. Locating adverbials, also known as "frame adverbials," indicate the time at or within which a situation obtains. They may have internal structure, including temporal clauses.

3. The features needed for temporal expressions must be established for each language. Flexible and deictic adverbials are common. Other features vary, depend on the tenses and other temporal forms in a language. The approach to features is like that proposed for French in Kamp & Rohrer 1989.

4. Ogihara 1989 shows that *will* and *would* do not follow the standard Reichenbachian account, and must be dealt with separately in a systematic account. He presents examples similar to 8c, with an analysis different from the one suggested here.

5. In marked uses, open situations (statives, and events with the imperfective viewpoint) can advance a narrative. The receiver infers the initial or final endpoint.

6. I discuss finite clauses here; non-finite clauses have the same time as their main clauses, assuming pragmatic advancement or retraction.

7. Generally, when a clause depends temporally on a higher clause, SitT (t_3) in the higher clause is the relevant time. In cases like this SitT establishes OT; in other cases SitT in the main clause functions as RT in the lower clause. For discussion, with the examples showing the need for this provision, see Smith 1978.

8. There is a good deal of indeterminacy in such cases, depending partly on whether the situations are open or closed, and partly on pragmatics.

9. In structures like this, verbs like *arrive, leave* are often taken to indicate a time in the future, especially in the progressive. See Smith 1978.

10. See Abusch 1988 for discussion.

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A Discourse-Level Approach to the Past Perfect in Narrative*

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Abstract

Accounts of the past perfect so far have concentrated on the semantics of the form and, more recently, on the role of inferencing patterns based on commonsense reasoning about the world. However, on both types of accounts a number of apparent vagaries concerning acceptability conditions on the past perfect remain. We argue in this paper that these vagaries disappear if some general discourse principles are taken into account, as well as the structure of the discourse in which the past perfect occurs. To illustrate this we focus on the use of the past perfect in narrative discourse. After outlining the set of relevant discourse principles, we show how the function of past perfect sentences in narrative is determined by the way these principles interact with the properties of narrative discourse.

The structure of the paper is as follows. We start off with a brief introduction on existing analyses of the past perfect, and illustrate by means of some examples the kinds of problems that remain unaccounted for in these analyses. In section 2 we introduce the framework in which we propose to address these problems. We outline the semantics of the past perfect we adopt, and describe how we conceive the properties of narrative structure relevant to the problems we address. In section 3, we sketch the general discourse principles we invoke, and show how these principles interact with the structure of narrative. In section 4 we introduce a further discourse constraint that applies only to narratives, and discuss how this constraint imposes restrictions on the use of the past perfect. In the final section we summarize how the proposed approach allows us to account for the problems outlined in the introduction, and present our main conclusions.

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1. Introduction

Most accounts of the past perfect implicitly or explicitly adopt a Reichenbachian framework, in which a past perfect sentence denotes an event or state anterior to a past reference time. On such a view it is hard to explain why the past perfect in (1a) sounds odd:

(1) (a) Ewan poured himself a cup of coffee. ?He had entered the house.
(cf. *Ewan entered the house and poured himself a cup of coffee.*)

The Reichenbachian definition suggests that a past perfect can be used felicitously in a discourse as long as the state of affairs it combines with can be situated before a given time of orientation in the past. The event 'Ewan poured himself a cup of coffee' can plausibly be thus situated; nevertheless the discourse is less than acceptable.

Furhtermore, a small change, which does not affect the temporal relation between the described situations, will make the discourse acceptable:

(1) (b) Ewan poured himself a cup of coffee. He had entered the house feeling tired, but now he was beginning to feel better.

This suggests that acceptibility conditions for the past perfect cannot be formulated solely in terms of temporal order between the situations talked about.

An alternative view of the past perfect is proposed by Moens (1987), who defines it in terms of the structure associated with events in a discourse. In Moens' approach, an event always has a complex structure, or *nucleus*, associated with it. Part of this complex structure consists of the *consequent state* of the event, defined as any state of affairs seen by the discourse participants as brought about by the event. Verb forms in the perfect make reference to the consequent state of the event the perfect combines with.

This idea predicts that as long as a state of affairs brought about by the occurrence of an event is salient at a particular past time, the past perfect of the event can be used of that time. But this still does not account for the oddity of (1a) in contrast with (1b). There is a salient consequence of the event 'Ewan entered the house' in force at the time we have reached, namely Ewan being in the house; yet the past perfect is infelicitous.

Finally, Lascarides & Asher (1991) have argued recently that the meaning of the past perfect must be defined not at the level of sentence semantics but at the discourse level. More specifically, they claim that the past perfect acts as a syntactic discourse marker indicating that only a restricted set of discourse relations can apply between the past perfect sentence and an event sentence which precedes it. While this approach offers some important new insights into the discourse role of the past perfect, it still leaves the problem of (1a)–(1b) unresolved. Even in the framework of Lascarides & Asher, it is unclear why (1b) is more acceptable than (1a), since the discourse relation between the past perfect sentence and the preceding event is not different in any obvious way.

We propose in this paper that the contrast between examples like (1a) and (1b) can only be elucidated in an approach which pays attention not only to the semantics (even 'discourse oriented' semantics) of the past perfect, but also to the structure of the discourse where the past perfect sentence appears. In the next section, we outline the general framework for our proposal.

2. General framework

2.1 The semantics of the past perfect

Workers in English grammar (e.g. Leech 1971, Comrie 1976) treat the past perfect as an ambiguous category, either a "past-in-the-past" or a "perfect-in-the-past". This is a view we also adopt. We define the perfect-in-the-past use of the past perfect as ascribing a consequent state to a contextually determined time. The past-in-the-past, in contrast, states the occurrence of an event prior to a contextually determined time.[1] The discourse in (2) contains an example of a perfect-in-the-past in a narrative:

(2) When he saw Freddy Malins coming across the room to visit his mother Gabriel left the chair free for him and retired into the embrasure of the window. The room had already cleared and from the back room came the clatter of plates and knives. (Joyce, *The Dead*, p. 189)

The past perfect sentence conveys that at this point in the narrative the stative proposition 'The room has cleared' could be asserted – either by an anonymous observer or by the character Gabriel. The compatibility with already gives syntactic support to this intuition (cf. Vlach 1981). Compare this to the following passage from the same story:

(3) Mr Browne took another sip of his whisky and said, with sidling mimicry:
'Well, you see, I'm the famous Mrs Cassidy, who is reported to have said: "Now, Mary Grimes, if I don't take it, make me take it, for I feel I want it."' His hot face had leaned forward a little too confidentially and he had assumed a very low Dublin accent, so that the young ladies, with one instinct, received his speech in silence. (Joyce, *The Dead*, p. 181)

Here, it would be counterintuitive to say that the past perfect clauses denote consequent states – indeed, it is not clear what the consequent states of the events 'he leaned forward' and 'he assumed a very low Dublin accent' could be in this context. Instead, the clauses convey that Mr Browne performed these actions at some point prior to the

[1] This is essentially in line with the Discourse Representation Theory (DRT) approach to the past perfect (e.g. Kamp & Reyle, forthcoming), except for the fact that in DRT the ambiguity is more complex. For our purposes, however, the traditional dichotomy will suffice.

time in the narrative we have reached, presumably as he was telling the joke. Syntactically, this reading is supported by the fact that the clauses cannot combine with already.[2]

In addition, we adopt from DRT the view that event sentences and state sentences play distinct roles in narrative discourse. However, we also propose to draw a distinction between the two types of sentences at the representational level, along the lines of Galton (1984), to capture their distinct discourse roles. We will say that event sentences introduce events as discourse referents, while state sentences ascribe propositions to times.[3] In the following section we will discuss briefly the relationship between the different roles of events and states at the discourse level, and the structure of narrative.

2.2. The structure of narrative discourse

As already pointed out, our analysis of past perfects is confined to narrative discourses. The precise definition of narrative lies beyond the scope of the paper; but what we say about the structure of narrative can be seen as a partial definition. For now, we simply assume that novels and short stories constitute examples of narrative discourse.

It is uncontroversial that on the basis of the co-operative principle (cf Grice 1975: 45) a reader will assume a text to be coherent, i.e. that eventualities in the discourse are related to each other in some way, even if this is not explicitly marked. What relations obtain between eventualities depends at least in part on the structure of the discourse at hand. In narrative, the relation of *temporal ordering* has long been seen as the primary source of coherence, and the one distinguishing narrative from other discourse types (cf. Labov 1972, Fleischman 1986, Givon 1987). However, the fact that one event can be interpreted as occurring after another will not necessarily lead to narrative coherence:

(4) A car stopped in the car park. Anna sliced some radishes.

The fact that the events in (4) can plausibly be interpreted as happening consecutively does not make the discourse coherent. Example (5), in contrast, does not sound odd:

(5) A car stopped in the car park. Anna looked up from her work and walked over to the window.

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2 Another important difference between the two types of past perfect is that the past-in-the-past has the capacity to sustain narrative progression, while the perfect-in-the-past does not. We will not go into that here; see Caenepeel & Sandström (in preparation).

3 While this view is not the one adopted in standard DRT, where both events and states are treated as individuals, it is not in conflict with it either. Kamp & Rohrer (1989 (ms): 29ff) point out that this approach has some advantages and is compatible with the theory as a whole. Nevertheless they opt for treating states as individuals, because it "simplifies the formulation of the entire system of temporal interpretation rules" (ibid., 30). We feel, however, that making a more principled distinction between events and states captures their different discourse functions rather more elegantly. This position is clarified and argued in more detail in Caenepeel & Sandström (in preparation).

For a narrative discourse to be well-formed, events must be connected by a more than temporal relationship. In the case of (5), we will not only infer that the event 'Anna looked up' happened after the event 'the car stopped', but also, and more importantly, that the noise of the car stopping is what made Anna look up and walk over to the window. Following Moens (1987) we call this type of relationship a *consequential* one. Consequentiality subsumes a family of more specific relations:

An event e' is consequential upon an event e if

i. e causes or takes part in causing **e'**;
ii. e creates or takes part in creating the appropriate conditions for **e'** to take place;
iii. e evokes or is part of what evokes **e'** as a response; or
iv. one of the relations (i)-(iii) holds between e and **e'** together (and possibly more events) and another event **e"** (or several other events).

(i) is Moens' subrelation of *causation*; (ii) is a generalization of his *enablement* relation that includes planned or conventionalized sequences of actions; and (iii) is a relation which (for reasons we cannot go into here) cannot be subsumed under either (i) or (ii).

(5) differs from (4) in that it describes a coherent series of events, related to each other by consequentiality. We call such a series of (at least two) consequentially related events an *episodic structure*. We hold that the concept of an episodic structure is crucial to the representation of narrative structure. The episodic structure with its governing relation of consequentiality is essential for how event sentences are interpreted, since each new event has to be incorporated into the current episodic structure. But episodic structures are important also because the *narrative timeline* is projected from them.[4]

The different roles played in narrative discourse by event and state sentences can now be specified further. The event referent introduced by an event sentence will be added to the current episodic structure, by virtue of being consequentially related to an earlier event. In the nature of the consequentiality relation, the new event will normally be interpreted as moving the story ahead on the narrative timeline. The proposition denoted by a state sentence, in contrast, will be evaluated, i.e. taken to hold or be asserted, at the time on the narrative timeline reached by the current episodic structure. Standardly, states are said to "overlap" with the eventuality which precedes them. It is worth noting, however, that the mere temporal relationship of truth of a stative proposition at a context-provided time is not a sufficient condition for coherence:

(6) I opened the door. ?My hair was black.

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[4] The narrative timeline as we see it has several properties in common with the real timeline we use in interpreting other kinds of discourse. One important way in which it differs from it, however, is that it does not stand in a clear relationship with an utterance event. For a more detailed discussion of this see Caenepeel (1989): 17–22; also Caenepeel & Sandström (in preparation).

Although the truth-interval of the state 'My hair be black' may overlap with the temporal location of the event 'I open the door', (6) is odd. This is because it is difficult to impute a *non*-temporal coherence relationship between the state and the immediate context. Such a relationship *can* be imputed in (7), which consequently is not odd:

(7) I opened the door. My hair was wet (and the sudden blast of cold air made me shiver).

We will return to the contextualization of states in narrative discourse in section 3.2.

Finally, it is worth noting that a narrative typically consists of several episodic structures. These episodic structures will be placed along the same timeline, but may be separated from each other by a gap, a commentary passage by the narrator, a descriptive or perspectivized discourse segment, etc. They may also run concurrently (i.e. in parallel) along the narrative timeline. The start of a new episodic structure will often be reflected in the layout of a text by means of a paragraph or chapter break.

3. The past perfect in narrative

Let us now return to the problematic examples (1a) and (1b):

(1) (a) Ewan poured himself a cup of coffee. ?He had entered the house.
(b) Ewan poured himself a cup of coffee. He had entered the house feeling tired, but now he was beginning to feel better.

(1b) differs from (1a) in that it adds new information about the event of Ewan entering the house, namely how he felt; in addition, that information is relevant in the context, in that it enables the reader to evaluate in what sense Ewan was beginning to feel better.

Two general discourse constraints are at work here, which can be formulated thus:

(I) The Information Status Constraint
Each new sentence in a discourse must contain new information.

(II) The Contextual Relevance Constraint
The new information contained in a sentence must cohere in a significant way with its immediate context.

In the following sections, we will discuss how these constraints interact with the structure of narrative discourse as outlined above.

3.1 The Information Status Constraint

The Information Status Constraint appears obvious and simple, insofar as it states that a new sentence cannot just repeat what has already been said, but must assert something not yet asserted. As such it explains why (8a–b) are pragmatically unacceptable:

(8) (a) Ewan went back into the house. ?He went back into the house.
(b) Ewan went back into the house and poured himself a cup of coffee. ?He had gone back into the house.

Its effects in narrative, however, turn out to be more complex than so. Consider (9a):

(9) (a) Alice walked towards John. ?She reached him.

This discourse is clearly non-optimal, even though the reaching has not been asserted – it appears to be so strongly implied by the asserted walking process that it acquires the status of given information. A process of walking towards carries a default inference of reaching, so that the mere occurrence of the reaching event is not sufficiently new to belong by itself in a sentence. Non-inferrable information (i.e. something besides the mere occurrence of the event) needs to be added, as in (9b):

(9) (b) Alice walked towards John. She reached him slightly out of breath.

Note that although the adverbial phrase in (9b) is syntactically subordinate, it is informationally superordinate. The reaching event, inferred and hence given, serves as a "hook" for the information that Alice was slightly out of breath, which is in focus.[5]

A parallel to this can be found in the nominal field. Consider the examples in (10):

(10) (a) John bought a house. ?It had a roof.
(b) John bought a house. It had a thatched roof.
(c) John bought a house. The roof was thatched.

A house by default will be taken to have a roof, just as walking towards a point by default implies reaching that point. Hence, that property cannot by itself constitute a new sentence (10a). However, it can be used as hook for additional information (10b). Again, although in (10b) the roof is head of the noun phrase, it is subordinate in informational terms to the property of being thatched. This can be syntactically reflected by making the roof the topic of the sentence (10c).[6]

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[5] This also explains why the Information Status Constraint applies only to main clauses. Consider, for example, the following discourse:

Alice walked towards John. When she reached him, she whispered something in his ear.

The when-clause can felicitously contain nothing but inferrable information, because it functions as the topic of the sentence. For an analysis of when-clauses in this framework, see Sandström (in preparation).

[6] The peculiarity of (9a) and (10a) recalls Levinson's (1987:402) *Principle of Informativeness*, which instructs a speaker to *minimization*, i.e. to "say as little as necessary", and a recipient to amplify the informational content of the message accordingly, specifically by assuming "that stereotypical relations obtain between referents or events, UNLESS (i) this is inconsistent with what is taken for granted, [or] (ii) the speaker has broken the maxim of Minimization by choosing a prolix expression." Violating Information Status means being prolix, and indeed, the effect of (9a) is to imply that stereotypical relations do *not* obtain between walking and reaching. If non-stereotypical relations are known to obtain, the discourse will be felicitous. Thus if John is the proud father of one-year old Alice, who is taking her first unassisted walk, the discourse ceases to be odd. Similarly (10a) will be acceptable where ste-

These observations affect our formulation of the Information Status Constraint, and this in turn has consequences for the use of the past perfect in narrative. *Given* information is not only *asserted* information; *inferred* information is also given. In processing a narrative, a reader infers the occurrence of certain events which are not explicitly mentioned. These assume the status of given information, and cannot form the sole content of a sentence. We can reformulate the Information Status Constraint as follows:

> **(I') The Information Status Constraint (second version)**
> Each sentence must contain new information, i.e. assert something which has not yet been asserted and which is not inferrable from preceding discourse.

We distinguish between two kinds of inferred events, *event presuppositions* and *event implications*. Following Molendijk (1992), we define an event presupposition as an event which is (immediately) anterior to an explicited event, and presupposed by it; and an event implication as an event which is (immediately) posterior to an explicited event, and implied by it. This distinction is best illustrated by means of some examples:

(11) He got a bottle of wine from the cupboard and poured himself a glass. ?He had taken the cork out.

The information provided by the sentence <u>He had taken the cork out</u> can be inferred from the event '[He] poured himself a glass': it is *presupposed* by it, and because of this assumes the status of given information in the discourse. Compare this to (12):

(12) Alice walked towards John and whispered something in his ear. ?She had reached him.

The event 'She reached him' is presupposed by the event '[she] whispered in his ear'; in this respect (12) is similar to (11). However, as we have seen, the same event is *also* an *implication* of the process 'Alice walked towards John'. Hence, it cannot form a sentence at its iconic place in the narrative, since it will already be inferred at that stage. In contrast, the event in (11) '[he] took the cork out', which is presupposed by '[he] poured himself a glass', does *not* at the same time constitute an implication of 'He got a bottle of wine from the cupboard'. Thus, it *can* be expressed at its iconic place in the narrative. The contrast between (13a) and (13b) illustrates this.

(13) (a) He got a bottle of wine from the cupboard, took the cork out and poured himself a glass .
(b) Alice walked towards John, ?reached him and whispered something in his ear.

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reotypical relations do not obtain between houses and roofs, say if John makes a business of buying ruined houses, which do not necessarily have roofs.

While the Information Status Constraint is a general discourse constraint, event inferencing in narrative discourse is intimately tied up with the notion of an episodic structure as a series of consequentially related events. Non-explicited events will be inferred and assume the status of given information precisely because the episodic structure must cohere in terms of consequentiality. Consider (14):

(14) He left his house, locked his front door, and drove off to work.

In order to build an episodic structure out of the explicited events in (14), a reader will have to infer more events. Consider the third clause, [he] drove off to work. The two preceding events do not fully create the appropriate conditions for the event described. In order to drive off to work, the male protagonist must also walk over to where his car is, open the car door, get in, and start the engine. All these events must be inferred before the driving off-event can be added to the episodic structure. Thus, the mere occurrence of one of them cannot subsequently be reported in a past perfect clause. But it can be reintroduced if additional information about it becomes relevant, as in (15):

(15) He left his house, locked his front door, and drove off to work. He had entered the car without noticing a bulky shape in the back seat, but as he turned into the parking lot he caught a glimpse of something in the rear view mirror.

Finally, consider the following example:

(16) 'And Captain Lingard has lots of money,' would say Mr Vinck solemnly [...], 'lots of money, more than Hudig!' [...] You know, he has discovered a river.'
That was it! He had discovered a river! That was the fact placing old Lingard so much above the common crowd of sea-going adventurers [...] (Conrad, *Almayer's Folly*, p. 10)

(16) seems to suggest that the Information Status Constraint as we have formulated it is too strong: the information provided by the sentence He had discovered a river has already been asserted explicitly, but can nevertheless be reasserted by itself in a new sentence, without new information being added. When the event is reasserted, however, it is being reconsidered by a character in the story (the young Almayer, as is evident from the larger context). The sentence is the surface realization of an underlying parenthetical (viz. 'he thought', or 'he said to himself'), and it is the implied perspective on the event which is new at this stage. Examples involving this type of point of view refraction do not invalidate Constraint I'. Rather, they show that a discourse may have several levels, and that the information status of sentences may differ at different levels.

In section 4.2. we will discuss the second discourse constraint referred to at the beginning of section 4, and its repercussions for the use of the past perfect.

3.2. The Contextual Relevance Constraint

The Contextual Relevance Constraint, as formulated in (II) above, states that each new sentence in a discourse must cohere with its immediate context in a significant way. In this section we focus on the link between this constraint and the event–state distinction, and on what this means for the use of the past perfect in narrative.

We emphasized earlier that event and state sentences play different roles in discourse, and that this difference cannot be formulated in purely temporal terms. We characterized the contextualization of an event sentence in narrative discourse: it introduces a new discourse referent which will be contextually relevant if it can be incorporated into the current episodic structure. Contextual relevance for events depends on the establishment of consequential relations – and here, as discussed, event inferencing plays a crucial role.

The past perfect, however, is a *stative* operator (cf. Moens 1987). A stative sentence does not introduce a new discourse referent, but ascribes a proposition to a time on the narrative time line. This has important repercussions for the way states in general, and past perfects in particular, are contextualized. Consider the following example:

(17) I went in on tiptoe. The room through the lace end of the blind was suffused with dusky golden light amid which the candles looked like pale thin flames. He had been coffined. (Joyce, *The Sisters*, p.12)

After the first sentence, the current episodic structure of which the event there described forms a part ceases to grow. Instead, the point on the timeline which has been reached when the first state is introduced becomes an *anchoring point*, at which that state (and any subsequent ones) will be evaluated. The focus of the discourse shifts from narrative development to the properties of entities, places and characters – in this particular case of the room entered by the "I-protagonist". Again, the relevance of such properties will arise from contextual considerations. The mere fact that a state holds at a particular time is not sufficient for coherence, as we saw above. As referents or locations are introduced, some, but not all, of their properties become relevant; and properties which may be irrelevant in an initial description may become relevant at a later stage.

Thus, with the introduction of a stative sentence in a narrative, an anchor is "dropped", so that narrative movement (propelled by consequentiality relations between events) is suspended. As a result, discourse relations other than consequentiality will become salient. These include *Background*, *Explanation*, *Parallel* and *Contrast*. *Point of view* may constitute an additional source of coherence for stative sentences in a discourse. As argued in Caenepeel (1989), one of the important properties of the anchoring point at which a stative proposition in a narrative is evaluated is that it may be activated as a *point of view centre*, i.e. a deictic centre coinciding with the perspective of one or more characters in the text.[7]

As past perfect sentences are stative, the contextualization principles just outlined also govern their behaviour in narrative. This means that

— the point in time of which a past perfect proposition is predicated functions in the discourse as an anchor;

— a past perfect sentence is contextualized by means of discourse relations other than consequentiality;

— the anchoring point at which a past perfect proposition holds may function as an empty deictic centre (descriptive use) or be activated as a point of view centre (perspectivized use), or hover between the two.

Let us recapitulate. We have seen that the past perfect in narrative is subject to two general discourse constraints. To understand fully the implications of the *Information Status Constraint* for narrative, we have introduced the notion of *event inferencing*. We have also drawn attention to the fact that a past perfect sentence may either *introduce* an event not previously asserted or inferred, or *reintroduce* an event that has already been asserted or inferred in order to supply further information about it; and we have discussed the repercussions of this at the discourse level. Finally, we have characterized the way in which a past perfect sentence is contextualized in narrative, by highlighting how *Contextual Relevance* translates for stative sentences in general. In the next section, we turn to a final constraint affecting the past perfect in narrative.

5. Monotonicity of episodic structures

We have argued that for a past perfect sentence to be used felicitously in a discourse it must meet the Information Status Constraint and the Contextual Relevance Constraint. Both of these constraints are met in the following example:

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[7] The stative sentences in (17) above hover somewhere between objective description and subjective experience: it is possible to interpret them as the content of the I-protagonist's perception as he enters the room, but this is not necessary for an adequate understanding of the text. In other cases a perspectivized interpretation is more compelling. In the following passage, for instance, the first stative sentence (It was nonsense and obscene nonsense) signals not only the suspension of the current episodic structure, but also the introduction of a point of view refraction. This point of view refraction is maintained in the stative sentences which follow it, all of which must be interpreted as reflecting the words (and the emotions) of Professor Erlin – up to the point where a new event sentence (He held his nose) takes us back to the current episodic structure:

> [...] and at these Professor Erlin lost his wonted calm: he beat the table with his fist, and drowned all opposition with the roar of his fine deep voice. It was nonsense and obscene nonsense. He had forced himself to sit the play out, but he did not know whether he was more bored or nauseated. If that was what the theatre was coming to, then it was high time the police stepped in and closed the playhouses. He was no prude and could laugh as well as anyone at the witty immorality of a farce at the Palais Royal, but here was nothing but filth. With an emphatic gesture he held his nose [...] (Maugham, *Of Human Bondage*, p. 110)

(18) He took two dirty glasses from the table and filled them with brandy. ?He had rinsed them out, and the glasses glittered in the sunlight.

The event introduced in the past perfect sentence He had rinsed them out is new (not previously asserted nor inferrable), and it is relevant in that it gives the reader the background for interpreting the next clause. Nevertheless the discourse is non-optimal.

We argue that a third constraint is at work here, specific to narrative discourse. We refer to it as the *Monotonicity Constraint*, and it can be paraphrased as follows:

> **(III) Monotonicity of episodic structures**
> The current episodic structure is only open at its right end; two events entered as adjacent cannot be made non-adjacent through the later insertion of a third event.

(18) violates this constraint, because the event of rinsing the glasses has to be placed between the two events in the preceding sentence, which have been entered as adjacent. A consequentiality relation between the two events has been established, and the Monotonicity Constraint states that this cannot be undone retrospectively.

Constraint III excludes a past perfect from *introducing* an event forming part of the *current* episodic structure. It does not exclude it from *reintroducing* an event from the current episodic structure – provided, of course, that the Information Status Constraint is met. (15) above is an example. The Monotonicity Constraint also does not exclude a past perfect from introducing an event which forms part of *another* episodic structure than the current one. As we pointed out in section 2, the narrative timeline may contain several episodic structures. A past perfect may for instance introduce an event which is part of an episodic structure *parallel* to the one being developed:

(19) "I was out last night," she said. "At a meeting." [...] "The child tells me there was another fire."
"Well, it wasn't exactly a fire," I said. The child had taken this mention of her name as an excuse to stop practising, and was standing now in the velvet doorway of the parlour, staring at me. (Atwood, *The Edible Woman*, p. 13)

The dialogue in (19) constitutes an episodic structure. The event of the child stopping practicing, although temporally concurrent with the dialogue, does not form part of the same episodic structure; it belongs to an episodic structure developed in parallel. We have emphasized that it is not temporal order as such that lends coherence to an episodic structure, but rather the consequentiality relations between the events. In the same way, the monotonicity constraint is not a constraint on the possible temporal orderings of events, but on the consequentiality chain between them, which can not be broken.

We also pointed out in section 2 that a narrative timeline is usually projected from several episodic structures, separated by "gaps", i.e. periods of silence. A past perfect may introduce an event which occurred in such a period of silence, as in (20):

(20) 'One minute!' called Mr Wilcox on receiving her name. He touched a bell, the effect of which was to produce Charles.

Charles had written his father an adequate letter – more adequate than Evie's, through which a girlish indignation throbbed. And he greeted his future step-mother with propriety. (Forster, *Howards End*, p. 183)

Recall also that page layout, chapter divisions etc. will reflect closures and openings of episodic structures. A new chapter will typically initiate a new episodic structure. Thus, an event sentence opening a new chapter will not yet form part of any episodic structure, so that a subsequent past perfect can introduce an event just preceding that event. If the first sentence of (21) constituted the opening sentence of a chapter, the rinsing event could be introduced felicitously by means of a past perfect:

(21) He filled the glasses with brandy. He had rinsed them out thoroughly, and the glasses glittered in the sunlight.

6. Summary and conclusions

To conclude, let us return to the contrast between examples (1a) and (1b):

(1) (a) Ewan poured himself a cup of coffee. ?He had entered the house.
(b) Ewan poured himself a cup of coffee. He had entered the house feeling tired, but now he was beginning to feel better.

We have argued that the acceptability of discourse segments depends on the structure of the discourse they appear in. It may therefore be unclear how acceptibility can be assessed out of context. We believe, however, that acceptability judgements for discourses out of context will depend at least in part on whether it is possible to *construct* a context in which the discourse would be felicitous. We will show that (1a) is felt to be odd because it is not possible to construct a context for it which meets all three of the constraints outlined above. We will also offer an example of a context for (1b) in which all three constraints *are* met; we claim that this explains why (1b) is felt to be coherent.

(1a) constitutes a narrative sequence; as such it can be contextualized either as the continuation of an episodic structure, or as the start of one. Let us pursue the former possibility first. (22a) places (1a) in the context of a current episodic structure:

(22) (a) Ewan shoved all the dead branches on a heap, made a big bonfire and collected his garden gear. He went back into the house, poured himself a cup of coffee and settled down to read a magazine. ?He had entered the house.

The sentence <u>He had entered the house</u> contains no information besides the occurence of the event. Since that occurrence has already been asserted, the past perfect sentence in (22a) violates the Information Status Constraint. To avoid this, the occurrence of that event should not have been asserted in the current episodic structure, nor be inferrable from it. This requirement is met in (22b):

(22) (b) Ewan shoved all the dead branches on a heap, made a big bonfire and collected his garden gear. He poured himself a cup of coffee and settled down to read a magazine. ?He had entered the house.

But now the Monotonicity Constraint is violated: the sentence He had entered the house undoes the consequentiality relation established between two earlier events ('[he] collected his garden gear' and 'he poured himself a cup of coffee') in the current episodic structure. In other words, it is impossible to construct a context where the discourse in (1a) can be part of an episodic structure. This explains why (1a) is rejected.

The alternative possibility is for (1a) to be contextualized as starting a chapter. In this case the information contained in the sentence He had entered the house can be new without Monotonicity being violated, since there will be no current episodic structure. However, it remains difficult to create a context in which Contextual Relevance can be met.[8] Now consider (22c):

(22) (c) Ewan shoved all the dead branches on a heap, made a big bonfire and collected his garden gear. He poured himself a cup of coffee and settled down to read a magazine. ?He had entered the house feeling tired, but now he was beginning to perk up.

Here, the Information Status Constraint and the Contextual Relevance Constraint are met, since new information is supplied which coheres with neighbouring discourse. But the past perfect sentence still violates the Monotonicity Constraint, by breaking up the consequentiality chain of the current episodic structure. It follows that for all three constraints to be met, the event of Ewan entering the house must be given at this point. Since the event is non-inferrable, it must be asserted at its iconic place within the episodic structure. (22d) constitutes the type of context which makes (1b) acceptable:

(22) (d) Ewan shoved all the dead branches on a heap, made a big bonfire and collected his garden gear. He went back into the house, poured himself a cup of coffee and settled down to read a magazine. He had entered the house feeling tired, but now he was beginning to perk up.

We have shown in this paper that important restrictions on the use of past perfect sentences in narrative discourse arise from the interaction between general discourse principles and the structure of narrative. We introduced two general constraints, the Infor-

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[8] But not impossible. The following discourse, for instance, would be acceptable as the opening section of a chapter, where the preceding chapter closed with Ewan being outside and getting very chilly:

> Ewan poured himself a cup of coffee. He had entered the house and felt he needed to get warm again.

mation Status Constraint and the Contextual Relevance Constraint, and showed how these affect the felicity conditions for the past perfect in narrative. We also introduced a third constraint specific to narrative discourse, the Monotonicity Constraint. Central to our argument has been the notion of an episodic structure as a sequence of consequentially related events introduced by adjacent event clauses. The episodic structure affects the role of the Information Status Constraint in narrative, in that building an episodic structure involves inferring the occurrence of events that have not been asserted explicitly, and assigning them the status of given information. It affects the role of the Contextual Relevance Constraint in narrative, since the contextual relevance of an event depends on whether it can be incorporated into the current episodic structure, and that of a state on how it coheres with this structure. The Monotonicity Constraint, finally, imposes immediate restrictions on the construction of an episodic structure in narrative.

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The Pluperfect in Narrative Discourse

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1 Introduction

An essential part of text interpretation involves calculating the rhetorical relations between the sentences in a text, and the temporal relations between the events they describe (Hobbs 1985, Thompson and Mann 1987, Hovy 1988, Scha and Polanyi 1988). In this paper, we investigate how the pluperfect tense affects both these aspects of interpretation. We will argue that the effect of the pluperfect on rhetorical structure must be encoded in a formal theory of pragmatic implicature. We will provide an account of the pluperfect in narrative discourse within a framework called DICE (standing for Discourse and Commonsense Entailment), which is designed to compute temporal implicatures for natural language texts (Lascarides and Asher 1991). We will examine in formal detail how the pluperfect affects temporal structure and rhetorical structure, and assess the role that given and new information, shift in perspective, and contextual relevance impose on coherent discourse.

2 The Puzzles

2.1 Interaction and Relevance

Reichenbach (1947) distinguishes the semantics of the simple past and the pluperfect, and Kamp (1991a) extends his ideas to provide an account of why (1) and (2) are different.

(1) Max stood up. John greeted him.

(2) Max stood up. John had greeted him.

Reichenbach represents tense as a tripartite temporal relation between speech time (ST), event time (ET) and reference time (RT). Kamp implements several extensions. First, he introduces a further temporal entity called the *temporal perspective point* (TP), and reanalyses tense as a relation between the *four* times ET, RT, TP, and ST. Second, he provides an algorithm for calculating the RT and TP of the current clause, given the discourse context. This enables him to calculate the temporal structure of multi-sentence discourses.

Kamp uses this extension to explain why time 'moves backwards' from the simple past to pluperfect clauses in (3), but 'moves forward' from one pluperfect clause to another; to explain how the the temporal adverbials in (4) induce a matching between the textual order of the events and the descriptive order, contrary to (2); and to account for the coherent (5a,b,c) vs. the incoherent (5a,b,d).

(3) a. Max arrived at the summit at midday.
  b. He had got up at 5:30am,
  c. had prepared his lunch,
  d. had chosen his route, and
  e. had passed base camp before 7am.

(4) At 6pm, Max left for the office. At 9:15pm, he had already passed the station.

(5) a. John arrived on 1st September.
  b. On the 4th he left for Frankfurt.
  c. The next day, his wife telephoned.
  d. ?The next day, his wife had telephoned.
  e. The next day, his wife had already telephoned six times.

In particular, the incoherence of (5a,b,d) is explained as follows: The departure for Frankfurt is the TP with respect to which (5d) is analysed. Because (5d) is in the pluperfect, the ET of the telephone call must precede the TP. On the other hand, the adverbial *the next day* means that the ET cannot precede TP. This makes (5d) uninterpretable. But the acceptability of (5a,b,e) and (6) force Kamp to assume an ambiguous analysis of the pluperfect.

(6) a. John arrived on the 1st of September.
  b. He had left London on 1st July.
  c. The next day, his wife had telephoned.

In order to ensure that (5a,b,e) and (6) are satisfiable while retaining the explanation of why (5a,b,d) is unacceptable, he provides another definition of the pluperfect where ET and TP *coincide*. But the ambiguous analysis of the pluperfect undermines the analysis of (5a,b,d); for the latter definition of the pluperfect makes this incoherent text coherent. So before we can assess that (5a,b,d) is awkward, we must determine which definition of the pluperfect is appropriate in that particular context; and how this is done isn't stipulated.

Kamp's Reichenbachian account of the pluperfect is problematic in at least two further respects. Firstly, the algorithm for calculating RTs only takes syntax into account, and so the temporal structure of a text is syntactically determined. Consequently, there can be no explanation of why even though (7) has the same tense structure as (3), they are interpreted differently: no order is inferred between the events in (7b-d) while there is temporal progression is (3b-d).

(7) a. Alex was a very good girl by the time she went to bed yesterday.
  b. She had helped her mum with the housework.
  c. She had practised her piano.
  d. She had done all her homework.
  e. We all felt very good about it.

Intuitively, the temporal progression in (3b-d) is inferred from causal knowledge about the typical orders between the events and by the temporal information conveyed by the list structure. In contrast, there is no knowledge that enables such an inference in (7b-d). An explanation in these terms motivate the Interaction Desideratum: *The analysis of the pluperfect must interact in precise and systematic ways with the reader's causal knowledge, pragmatic maxims and the discourse type to yield appropriate temporal structures.* And a syntactic-based analysis of tense on its own fails to fulfil this.

The second problem is that, in line with the Reichenbachian approach, the semantics of tense appeals only to *temporal* relations. But consider texts (8) to (11).

(8) Max entered the room. He poured himself a cup of coffee.

(9) ?Max poured himself a cup of coffee. He had entered the room.

(10) Max poured himself a cup of coffee. He had entered the room feeling depressed, but now he felt much better.

(11) John turned round. Max poured himself a cup of coffee. He had entered the room by the side door.

Texts (8) and (9) attempt to describe similar temporal relations, and yet only (8) is acceptable. Similarly, (9), (10) and (11) describe similar temporal relations between the first event mentioned and the second, but only (10) and (11) are acceptable. One can view (8) to (10) as a manifestation of *contextual relevance*; a similar view is proposed in Caenepeel and Sandström (1992). One event being in the consequent state of the other is sufficient for simple past tensed text to satisfy the Contextual Relevance Constraint (cf. (8)), but it won't do on its own for the pluperfect in (9), although (10) and (11) show that additional information can ameliorate (9)'s incoherence. We can thus think of the pluperfect as a *discourse marker* that indicates that the range of possible connections that would make the clause 'contextually relevant' is restricted (relative to the possibilities for the simple past). These observations yield the following Relevance Desideratum: *The analysis of the pluperfect must take Contextual Relevance into account.* Fulfilling this desideratum requires the analysis of the pluperfect to interact in precise ways with the semantic content of the clause; this is outside the scope of Kamp's theory, since tense is defined purely in terms of temporal relations, and not causal or rhetorical relations.

Webber (1988) augments Reichenbach's theory by adding event-connections: the events described in a text must stand in part/whole or causal relations. However, her analysis of the pluperfect doesn't preclude the event described in the simple past being a consequent of the event described in the subsequent pluperfect clause, thus predicting, contrary to intuitions, that (9) is acceptable. One could add an appropriate constraint to her theory to block this. But no provision is made for exploring how one would determine which event-connection the reader would infer given her background knowledge: she fails to satisfy the Interaction Desideratum. This means that a detailed explanation of why (9) is incoherent is not possible in Webber's framework as it stands.

2.2 Perspective Shift

A pluperfect clause can initiate a *perspective shift* such as those that occur in free indirect style (FIS), where the control over the proposition shifts from the author to a character in the text (Leech and Short 1981, Quirk *et al.* 1985). For example, consider text (12) (taken from Nakhimovsky 1988):

(12) a. The telephone rang:

b. It was Mme Dupont;

c. Her husband had eaten too many oysters for lunch.

d. The doctor recommended a change in lifestyle.

(12c) initiates FIS: Control over the proposition in (12c) is shifted from the author to Mme Dupont, because in contrast to (12b), (12c) reports *Mme Dupont's* perceptions (of what was said over the phone). The pluperfect plays a crucial role in creating FIS in (12), for replacing it with the simple past would mean that the author's perspective is maintained:

(12) c′. Her husband ate too many oysters for lunch.

We wish to explain this phenomenon and so we aim to fulfil the Perspective Desideratum: *The semantic framework used must be able to represent perspective, such as those that occur in indirect speech.*

2.3 Given and New Information

Caenepeel and Sandström (1992) discuss constraints on the information status of main clauses in narrative text. In agreement with Molendijk (1992), they argue that the reader forms bridging inferences that certain events occur, even if they're not mentioned in the text, and that these inferences are based on those events that *are* mentioned in the text. For example from text (13), one infers by default that John reached Alice: to use Molendijk's terminology, this is an *implicated* event.

(13) John walked over towards Alice and whispered something in her ear.

Caenepeel and Sandström argue that there is a rule for narrative discourse which stipulates that it is pragmatically inappropriate to mention implicated events in a main clause: This is a manifestation of the Gricean maxim, *be informative.* If it were encoded in the theory, it could explain the incoherence of (14), because the sentence with the pluperfect verb describes an event implicated by the contents of the first sentence.

(14) ?John walked over towards Alice and whispered something in her ear. He had reached her.

This discussion gives rise to the Information Desideratum: *The analysis of the pluperfect must take into account and make precise the Gricean maxim, Be Informative.* Kamp (1991a) does not satisfy this Desideratum, since he is not concerned with how the information status of propositions affects DRS construction.

3 The Proposed Strategy

We will formalise the discourse role of the pluperfect in DICE, modelling both its semantics and its pragmatic contributions in order to fulfil the above desiderata. In contrast to Kamp (1991a), we will examine the role that the reader's background knowledge plays in interpreting the pluperfect tense. The reason we devote attention to a *formal* account is because we assume that the reader's various knowledge resources on occasion yield conflicting conclusions about discourse structure (cf. Hobbs 1985, Lascarides and Asher 1991), and resolving the conflicts is arbitrary unless supported by an underlying logical consequence relation.

DICE encodes causal knowledge and pragmatic maxims, and is thus sufficiently powerful to satisfy the Interaction Desideratum. DICE also represents rhetorical relations, which we use to fulfil the Relevance Desideratum. We will finally augment DICE with *lexical information*; in particular, we will make use of *thematic roles* (Pustejovsky 1991, Dowty 1989)in our rules for constructing an appropriate discourse structure. Some of these roles will be filled by propositional attitudes; these will provide the means to represent perspective in indirect speech, thereby fulfilling the Perspective Desideratum. Furthermore, a Be Informative Constraint will be imposed on identifying thematic roles. So augmenting DICE with lexical information will also supply the means to satisfy the Information Desideratum.

We start with a brief overview of DICE; we then supply an account of the semantics and pragmatics of the pluperfect in narrative discourse.

4 A Brief Description of DICE

DICE (Lascarides and Asher 1991, in press) is a logical theory for determining the discourse relations between the segments of a text, and the temporal relations between the eventualities they describe. We take the basic building blocks of discourse structure to be propositions with a dynamic content, which we will represent, following Asher(in press), as DRSs. However, discourse relations may also obtain between more complex structures– segmented DRSs (SDRSs), which are defined recursively. In Segmented Discourse Representation Theory (SDRT) (Asher in press), an NL text is represented by a segmented DRS, which is a pair of sets containing respectively: the DRSs or SDRSs representing respectively sentences or text segments, and discourse relations between them. These structures are constructed in a dynamic fashion like DRSs.

Discourse relations modelled after those proposed by Hobbs (1985) and Mann and Thompson (1986) link together the constituents of an SDRS. We will use seven discourse relations: *Narration*, *Elaboration*, *Explanation*, *Background*, *Continuation*, *Parallel* and *Contrast*. The first four of these constrain temporal structure: *Narration* entails that the descriptive order of events matches their temporal order; an *Explanation* or *Elaboration* entail they mismatch; and *Background* entails temporal overlap.

The recursive nature of SDRSs give discourse structures a hierarchical configuration. Certain discourse relations in an SDRS impose a hierarchical structure; these subordinating relations are *Elaboration* and *Explanation*. The so-called *open constituents* to which new information can attach are the previous constituent or constituents it elaborates or explains. Thus the open clauses are those on the right frontier of the discourse structure (cf. Polanyi 1985, Grosz and Sidner 1986, Webber 1991), assuming that it is built in a depth first left to right manner.

DICE makes the following claims. First, the logical form of *sentences* do not encode movement of time through discourse. Instead, the current sentence is attached to the preceding discourse structure with a discourse relation; the process by which this is done takes the reader's background knowledge into account, and the resulting discourse structure determines how time moves through discourse. So, in contrast to Kamp (1991a), temporal structure is directly affected by the reader's knowledge. Here, we assume the reader's KB contains: the logical forms of the sentences; an assumption that the current sentence must attach at an open site (i.e., the text is coherent); all defeasible and indefeasible world and pragmatic knowledge; and the laws of logic.

The rules introduced below are shown in Lascarides and Asher (1991) to be manifestations of Gricean-style pragmatic maxims and world knowledge; we assume they form part of the reader's KB. A formal notation makes clear both the logical structure of these rules, and the problems involved in calculating implicatures. Let $\langle \tau, \alpha, \beta \rangle$ be the update function, which means "the representation τ of the text so far, of which α is an open node, is to be updated with the representation β of the current clause via a discourse relation with α". Let $\alpha \Downarrow \beta$ mean that α is a topic for β; let

e_α be a term referring to the main eventuality described by the clause α; and let $fall(m, e_\alpha)$ mean that this event is a Max falling. Let $e_1 \prec e_2$ mean the eventuality e_1 precedes e_2, and $cause(e_1, e_2)$ mean e_1 causes e_2. Finally, we represent the defeasible connective as as a conditional $>$ (so $\phi > \psi$ means 'if ϕ, then normally ψ'). The maxims for modelling implicature are then represented as schemas:[1]

- **Narration**: $\langle \tau, \alpha, \beta \rangle > Narration(\alpha, \beta)$
- **Axiom on Narration**: $\Box(Narration(\alpha, \beta) \rightarrow e_\alpha \prec e_\beta)$
- **Explanation**: $\langle \tau, \alpha, \beta \rangle \wedge cause(e_\beta, e_\alpha) > Explanation(\alpha, \beta)$
- **Axiom on Explanation**: $\Box(Explanation(\alpha, \beta) \rightarrow \neg e_\alpha \prec e_\beta)$
- **States Overlap**: $\langle \tau, \alpha, \beta \rangle \wedge state(e_\beta) > overlap(e_\alpha, e_\beta)$
- **Background**: $\langle \tau, \alpha, \beta \rangle \wedge overlap(e_\alpha, e_\beta) > Background(\alpha, \beta)$
- **Axiom on Background**: $\Box(Background(\alpha, \beta) \rightarrow overlap(e_\alpha, e_\beta))$
- **Background must be Relevant**: $\Box((\alpha > \beta) \rightarrow \neg Background(\alpha, \beta))$
- **Continuation**: $\langle \tau, \beta, \gamma \rangle \wedge \alpha \Downarrow \beta > Continuation(\beta, \gamma)$
- **Continuing Discourse Patterns**:
  $\Box(\langle \tau, \beta, \gamma \rangle \wedge \alpha \Downarrow \beta \wedge \phi(\alpha, \beta) \wedge Continuation(\beta, \gamma) \rightarrow \phi(\alpha, \gamma))$
- **Causes Precede Effects**: $\Box(cause(e_2, e_1) \rightarrow \neg e_1 \prec e_2)$

The rules for Narration and its Axiom convey the pragmatic effects of the textual order of events; by default, textual order mirrors temporal order. States Overlap, Background and its Axiom convey the pragmatic effects derived from aktionsart (states normally provide background information). Continuation and Continuing Discourse Patterns convey the pragmatic effects of the preceding discourse structure; they state that normally, the current clause γ continues to describe the same topic α as the preceding clause β did, and γ is related to α by the same discourse relation. Finally, that Causes Precede their Effects is indefeasible world knowledge.

We also have laws relating the discourse structure to the topic structure (Asher, in press): for example, A Common Topic for Narrative and Continuation state that any clauses related by *Narration* or *Continuation* must have a distinct, common (and perhaps implicit) topic, and Topic for Elaboration states that the elaborated clause is the topic:

- **A Common Topic for Narrative**
  $\Box((Narration(\alpha, \beta) \vee Continuation(\alpha, \beta)) \rightarrow (\exists \gamma)(\gamma \Downarrow \alpha \wedge \gamma \Downarrow \beta) \wedge \neg(\alpha \Downarrow \beta) \wedge \neg(\beta \Downarrow \alpha))$
- **Topic for Elaboration**
  $\Box(Elaboration(\alpha, \beta) \rightarrow \alpha \Downarrow \beta)$

The logic on which DICE rests is Asher and Morreau's (1991) Commonsense Entailment (CE). Three patterns of nonmonotonic inference are particularly relevant: The first is Defeasible Modus Ponens: if one default rule has its antecedent verified, then the consequent is nonmonotonically inferred. The second is the Penguin Principle: if there are conflicting default rules that apply, and their antecedents are in logical entailment relations, then the consequent of the rule with the most specific antecedent is nonmonotonically inferred. The third is the Nixon Diamond: if there

[1] Discourse structure and $\alpha \Downarrow \beta$ are given model theoretical interpretations in Asher (in press); e_α abbreviates $me(\alpha)$, which is formally defined in Asher (in press) in an intuitively correct way.

are conflicting default rules that apply but no logical relations between the antecedents, then no conclusions are inferred.

In interpreting (1), the KB contains $\langle\alpha, \alpha, \beta\rangle$, where α and β are respectively the logical forms of the first and second clauses.

(1) Max stood up. John greeted him.

(15) Max opened the door. The room was pitch dark.

The only rule that applies is Narration, and its consequent is inferred via Defeasible Modus Ponens. Hence the standing up precedes the greeting. In contrast, text (15) verifies the antecedents to *two* conflicting defeasible laws: Narration and States Overlap. By the Penguin Principle, States Overlap wins, because its antecedent entails Narration's. In turn, this entails that the antecedent to Background is verified; and whilst conflicting with Narration, it's more specific, and hence its consequent—*Background*—follows by the Penguin Principle. We call this double application of the Penguin Principle the Cascaded Penguin Principle.[2]

The Nixon Diamond provides the key to text incoherence (Lascarides and Asher, 1991). If the reader's knowledge resources are in irresolvable conflict, no conclusions about the discourse structure can be inferred. DICE exploits this account of incoherence in its approach to *discourse popping*. When a Nixon Diamond occurs in attempting to attach the current clause to the previous one, they don't form a coherent text segment. So the current clause must attach to one of the other open clauses. This results in a discourse pop.

5 The Semantics of the Pluperfect

DICE represents temporal information in two places: in the DRS representing a sentence, and in the discourse relations. Because of these two levels, we can preserve *sentential* equivalence between the simple past and pluperfect, while still maintaining that these tenses play different roles in *discourse*, by ensuring that different default rules for discourse attachment apply. This means that, in contrast to Hamann (1989) and Kamp (1991a), we can provide a *uniform* analysis of the pluperfect that both captures the equivalence between (16) and (17)—through sentential equivalence—and captures the different discourse roles of the simple past and pluperfect—through different rules for discourse attachment.

(16) John left the office after he phoned his lawyer.

(17) John left the office after he had phoned his lawyer.

The logical forms of (18) and (19) are respectively (18′) and (19′).

(18) John greeted Max

(18′) $[e,t][greet(j,m,e), hold(e,t), t \prec now]$

(19) John had greeted Max

(19′) $[s,t][s:[e][greet(j,m,e), s = cs(e)], hold(s,t), t \prec now]$

[2]The formal details of how the logic CE models these interpretations are given in Lascarides and Asher (in press). Although the double application of the Penguin Principle, as in (15), is not valid in general, we show that for the particular case considered here, CE validates it.

In (18′) the discourse referent e is a John greeting Max event, which holds at the time t preceding now. In (19′), s is the consequent state of the event of John greeting Max, and it holds at the time t which precedes now. We assume that the following relationship holds between an event and its consequent state:

- `Consequent States:` $\Box(holds(cs(e),t) \leftrightarrow (\exists t')(hold(e,t') \wedge t' \prec t))$

So a consequent state holds if and only if the event holds at an earlier time. This relationship means that (18′) and (19′) are truth conditionally equivalent, under the usual assumption that time is dense. The only difference is in the eventualities that are available for future anaphoric reference. This equivalence is contrary to Reichenbachian treatments, and we'll shortly show how it explains (16) and (17).

6 The Pragmatics of the Pluperfect

We now consider the pluperfect's role in discourse. We argued that one must fulfil the Relevance Desideratum: the range of possibilities for connecting a pluperfect clause to a simple past tensed one is smaller than the range of possibilities allowed for connecting a simple past tensed clause to a simple past tensed one (cf. (8) vs. (9)). We will show that for the above data, the discourse relations permitted between a simple past and pluperfect are exactly *Elaboration*, *Explanation*, *Parallel*, *Contrast*, and *Background*. This would be what one would intuitively expect, for these are the only discourse relations we consider that are compatible with a backwards movement of time in discourse.

We represent this constraint as defeasible knowledge, for (4) is an exception:

- `Constraint When Changing Tense` (CCT): $\langle \tau, \alpha, \beta \rangle \wedge sp(\alpha) \wedge pp(\beta) > C_{pp}(\alpha, \beta)$

(4) At 6pm, Max left for the office. By 9:15pm, he had passed the station.

CCT states that if a pluperfect clause β is to be attached to a simple past tensed clause α, then the discourse relation between them must be defined by C_{pp}, which is the disjunction of *Elaboration*, *Explanation*, *Parallel* and *Contrast*. (4) is an exception because the presence of the adverbial *by 9:15pm* forces a temporal progression and a discourse relation of Narration.

Consider CCT's impact on text (2), and contrast this with DICE's analysis of (1).

(1) Max stood up. John greeted him.

(2) Max stood up. John had greeted him.

In the interpretation of (2), the rules that apply are: Narration, States Overlap and CCT. By the Penguin Principle, one infers the consequent state of greeting and standing up overlap (by States Overlap), and that the clauses are related by C_{pp}; for both States Overlap and CCT are more specific than Narration and conflict with it. In addition, the following defeasible knowledge captures the intuition that if a standing up and a greeting are connected, and moreover, the connection is C_{pp}, then in the absence of information to the contrary, the relation *Explanation* is preferred (for out of the four choices, John's greeting Max explaining why Max stood up is the most plausible):

- `Greeting Law:` $\langle \tau, \alpha, \beta \rangle \wedge standup(e_\alpha) \wedge greeting(e_\beta) \wedge C_{pp}(\alpha, \beta) > Explanation(\alpha, \beta)$

Now the rules Background and the Greeting Law apply, and one infers *Background*(α, β) and *Explanation*(α, β).[3] So the consequent state of John greeting Max is still in force when Max stands up, and the greeting explains why Max stood up. Thus CCT helps us model the difference between simple past tensed texts and pluperfect ones.

Now consider texts (8) and (9); we infer that the discourse relation connecting the sentences in (8) is *Narration*. The laws that apply in the analysis of (9) are Narration, States Overlap and CCT. As in the analysis of (2), $overlap(e_\alpha, e_\beta)$ and $C_{pp}(\alpha, \beta)$ are inferred. But here, we don't have a law like the Greeting Law which allows us to infer which relation permitted by C_{pp} is most plausible, given the events described. We could infer Background, except that since pouring coffee normally entails that one enter the room where the coffee is, we see that β is not informative. So we fail to infer which of the four permitted discourse relations holds for (9), leading to incoherence.[4]

Now consider text (10). The default assumption in DICE is that one constructs the DRS for the whole *sentence* before one attempts discourse attachment. Using rules for constructing DRSs, the logical forms of the sentences in (10) are respectively α and β.

$$(\alpha) \quad \begin{array}{|l|}\hline e_1, j, t_1 \\ \hline e_1 : pour(j, coffee) \\ e_1 \prec now \\ hold(e_1, t_1) \\ \hline \end{array}$$

$$(\beta) \quad \begin{array}{|l|}\hline z, s_2, z', s_3, t_2, t_3 \\ \hline z = j \\ s_2 : \begin{array}{|l|}\hline e, t \\ \hline e : enter(z, room) \\ s_2 = cs(e) \\ hold(e, t) \\ \hline \end{array} \\ hold(s_2, t_2) \\ s_3 : feel\text{-}better(z) \\ z' = j \\ hold(s_3, t_3) \\ overlap(s_2, ??) \\ t_2 \prec t_3 \\ t_2 \prec now, t_3 \prec now \\ \hline \end{array}$$

The discourse use of the adverbial *now* in (10) is important to our analysis in two ways. First, it introduces an incomplete condition, according to which the event of pouring coffee overlaps with some accessible time or event. It is up to the process of anaphora resolution to find the appropriate event or time. In SDRT, however, anaphora resolution must take place after discourse attachment, and accessibility is redefined so that discourse referents declared in the appropriate DRSs of the SDRS that serves as the attachment point are accessible (see Asher, in press). There is only one attachment point in the structure built up so far for (10)–α; by our rules we must attach β there. By anaphora resolution we get that the event of pouring the coffee overlaps with the state s_3 of feeling much better. The second effect of the discourse use of *now* is that together with the shift in

[3] As in the Cascaded Penguin Principle, the predicates used are sufficiently independent that we can divide up the nonmonotonic reasoning in this way.

[4] There is a sense in which entering a room can be regarded as part of the preparatory phase of pouring coffee, which normally indicates that the text is an *Elaboration*. But entering a room is from an intuitive perspective not of the appropriate *granularity*, that it could be regarded as part of coffee pouring in the absence of other details. So we cannot infer from (9) alone that *Elaboration* is the most plausible choice out of the four; further information is required before we can make this inference.

the second clause from pluperfect to simple past, we get forward shift in time: thus, t_2 precedes t_3.

Now we must relate β to α with a discourse relation. The rules that apply are States Overlap and Narration. CCT does *not* apply, because we are not relating a pluperfect clause to a simple past tensed one. By the Cascaded Penguin Principle, we infer $Background(\alpha, \beta)$, and so the text is coherent and the second sentence in (10) describes the background circumstances when Max poured himself the coffee. If the comma in (10) is replaced with a full stop, then CCT does apply, as do States Overlap and Background. The additional material in (10) about depression, it seems to us, makes it possible to attach the second clause to the first with Background. If not, then we fail to attach the SDRS constructed from the second clause with α for the same reasons as in (9). But we have a strategy of accommodation here: upon failing to attach the second sentence to the first, as in (9), we attempt to attach the third sentence to the second to obtain an SDRS which one *then* attempts to attach to the first sentence. At this point, CCT won't apply either, and instead *Background* is inferred. The strategy for analysing text (11) involves more complex commonsense knowledge and for the sake of brevity, we won't go into a details here.

CCT fulfills the Relevance Desideratum, because it explains the difference in coherence between (8) to (11). It also explains the different temporal structures imposed in (1) vs. (2). We have also seen how Gricean constraints of informativeness crucially constrain discourse structure.

7 The Pluperfect and Temporal Adverbials and Connectives

We now explore the interaction between the pluperfect, temporal adverbials and connectives. Consider again (16) and (17).

(16) Max left the office after he telephoned his lawyer.

(17) Max left the office after he had telephoned his lawyer.

The clauses *Max telephoned his lawyer*, *Max had telephoned his lawyer* and *Max left the office* are represented respectively as α, α' and β:[5]

(α) $[e_1, t_1][phone(e_1), hold(e_1, t_1), t_1 \prec now]$

(α') $[s_1, t_1][s_1 : [e_1][phone(e_1), s_1 = cs(e_1)], hold(s_1, t_1), t_1 \prec now]$

(β) $[e_2, t_2][leave(e_2), hold(e_2, t_2), t_2 \prec now]$

And the semantics of the connective *after* is represented as follows:

- $after \rightsquigarrow \lambda\Phi\lambda P(\Phi[\lambda t, t \prec ??] \wedge P)$

In the analysis of (16), α and β combine with the connective *after* to produce the logical form (16′).[6]

[5] For the sake of simplicity, we have abbreviated $phone(max, lawyer, e_1)$ to $phone(e_1)$ and $leave(max, office, e_2)$ to $leave(e_2)$. Similarly abbreviations will occur regularly in this paper.

[6] The definition in SDRT of which antecedents are available for anaphoric reference predicts that the anaphor in *after* is the time t where Max leaves the office. We omit the details here.

$$(16')\quad \begin{array}{|l|}\hline e, t, e', t' \\ \hline leave(e) \\ hold(e,t) \\ t \prec now \\ phone(e') \\ hold(e',t') \\ t' \prec t \\ \hline \end{array}$$

The logical form of (17) is constructed in a similar way—save that we use α' instead of α—to produce (17′).

$$(17')\quad \begin{array}{|l|}\hline e_1, t_2, s, t_2 \\ \hline leave(e_1) \\ hold(e_1,t_1) \\ t_1 \prec now \\ s : \begin{array}{|l|}\hline e_2 \\ \hline phone(e_2) \\ cs(e_2) = s \\ \hline \end{array} \\ hold(s_2,t_2) \\ t_2 \prec t_1 \\ \hline \end{array}$$

(17′) is truth conditionally equivalent to (16′), and in particular they describe the same temporal structure: this arises from the truth conditional equivalence between α and α'.

However, (17′) fails to relate the *event times* of the leaving and phoning *directly*: t_2 is a time where the consequent state holds. This is rectified in the pragmatic component of DICE; specifically by a rule concerning the interaction between *after* and states. Sentence (20) indicates that *after* implicates an inceptive reading of states: once the room *became* dark, Max opened the door.

(20) Max opened the door after the room was dark.

This is captured in the following law: if the connective *after* modifies a state then that state is normally interpreted inceptively.

- **Inceptive:** $after(\beta) \wedge state(e_\beta) > incstate(e_\beta)$

We assume that $incstate(e)$ entails that the time discourse referent introduced in the corresponding DRS is the time where the state starts. By default, one constructs the logical form of whole *sentences* before one attempts discourse attachment to the preceding text. So the only rule that applies in the analysis of (20) is Inceptive (for no update function is in the KB); and by Defeasible Modus Ponens, the room being dark is interpreted inceptively, as required.

Now consider Inceptive's effect on (17). Again, by Defeasible Modus Ponens on Inceptive, we infer that the pluperfect clause describes a state that is to be interpreted inceptively. This entails that the discourse reference t_2 in (17′) is to be the time where the state starts: that is, t_2 is the time where the *event* of Max phoning occurs; i.e., the time t' in (16′). Hence the connective *after* in (17) will by pragmatics relate the two *event* times, as (16) does.

Unlike Hamann (1989), we have analysed (17) without having to assert that the pluperfect is analysed using a RT when it appears in the main clause, but no RT when it is in a subordinate clause. She is forced to do this to achieve the appropriate representation of (17). We do not use reference times at all, and contrary to Hamann, we have a *uniform* analysis of the pluperfect, which explains both the equivalent temporal structures of (16) and (17), *and* the distinct temporal structures of (1) and (2).

Now consider the coherent (5a,b,c) and (5a,b,e) and the incoherent (5a,b,d).

(5)	a.	John arrived on 1st September.	α
	b.	On the 4th he left for Frankfurt.	β
	c.	The next day, his wife telephoned.	γ
	d.	?The next day, his wife had telephoned.	δ
	e.	The next day, his wife had already telephoned six times.	ϵ

Our analysis of (5) will improve Kamp's, in that we won't need to augment the semantics of tense with an account of disambiguation in particular discourse contexts. Our semantics of tense is not ambiguous at all, but instead, the different interpretations of the tenses arise from pragmatic rules for discourse attachment.

The logical forms of (5a-b) are α and β, and as in text (1), Narration applies and $Narration(\alpha, \beta)$ is inferred.

(α) $\quad [e_1, t_1][arrive(e_1), hold(e_1, t_1), t_1 \prec now, t_1 = sept1]$

(β) $\quad [e_2, t_2][leave(e_2), hold(e_2, t_2), t_2 \prec now, t_2 = sept4]$

The logical forms γ, δ and ϵ of (5c-e) use the following representation of *the next day*:

- *The next day*$\phi \rightsquigarrow \lambda t[\phi'(t), day\text{-}after(t, t'), t' =??]$

The value of t' in the above must be identified with respect to the SDRS constructed so far. When analysing (5a,b,c), the only open clause to γ is β, and so given the treatment of anaphors in SDRT (which we gloss over here), the anaphor t' in the translation of *the next day* is β's time discourse referent t_2. Thus γ is the following:

(γ) $\quad [e, t][phone(e), hold(e, t), t \prec now, dayafter(t, t_2)]$

Similarly, δ and ϵ are given below:

(δ) $\quad [s, t][s : [e][phone(e), cs(e) = s], hold(s, t), t \prec now, dayafter(t, t_2)]$

(ϵ) $\quad [s, t][s : [e][phone(e), cs(e) = s], hold(s, t), t \prec now, dayafter(t, t_2), already(s)]$

Note that in γ, *the next day* identifies the time where the event of phoning holds, and in δ and ϵ, it identifies the time where the consequent state of phoning holds.

We look at (5a,b,c) first, and explore how γ attaches to the SDRS built so far. The task is to calculate the value of the function $\langle \tau, \beta, \gamma \rangle$. The truth conditions of γ entail that $t_2 \prec t$; thus because e_β and e_γ are events, we have $e_\beta \prec e_\gamma$. This is compatible with Narration, the only default law that applies. Thus $Narration(\beta, \gamma)$ is inferred, in agreement with intuitions.

Now we consider (5a,b,d); we must work out how δ attaches to β. And of the default rules we have so far, the ones that apply are: Narration, States Overlap, and CCT. We view the uninterpretability of (5a,b,d) as arising from an irresolvable conflict between these laws and a further default concerning the way states modified by *the next day* are interpreted. The default is that *the next day* gives an inceptive reading to states. This is similar to the implicatures that followed from *after*. There appears to be a general relationship between temporal expressions that indicate progression and the implicature that states are inceptive. This general interaction between states and adverbials of temporal progression is intuitively supported by the view favoured by Moens and Steedman (1988), Nakhimovsky (1988), and Webber (1988), that by default there must be some consequential relation between eventualities that are asserted to be in temporal progression. We capture this pragmatic knowledge as follows:

- **Inceptive Next Day** (IND): $\textit{the-next-day}(\alpha) \wedge \textit{state}(e_\alpha) > \textit{incstate}(e_\alpha)$

This law is added to the KB and it applies when updating β with δ. What's more, it creates irresolvable conflict. For on the one hand, IND and Narration entail the leaving precedes the phoning; on the other, CCT and States Overlap entail the opposite; and the antecedents of these laws aren't related. Thus no discourse relation can be inferred between β and δ.

Now we consider the analysis of (5a,b,e). We assume that *already* implicates overlap, in a rule that is more specific than the rules concerning inceptive readings resulting from adverbials of temporal progression. This is represented in the following schema where Φ stands for any cause-free information:

- **Already Overlaps:** $\langle \tau, \alpha, \beta \rangle \wedge \Phi(\alpha, \beta) \wedge \textit{already}(\beta) > \textit{overlap}(e_\alpha, e_\beta)$

By the Penguin Principle, Already Overlaps deems IND irrelevant. Consequently the above irresolvable conflict is resolved by this extra rule, and we infer $\textit{overlap}(e_\beta, e_\epsilon)$ (by Already overlaps and States Overlap), $C_{pp}(\beta, \epsilon)$ (by CCT) and $\textit{Background}(\beta, \epsilon)$. In contrast to (5a,b,d), no Nixon Diamond occurs, thus ameliorating that text's incoherence.

Finally, consider once again text (4):

(4) At 6pm Max left for the office. At 9:15pm, he had already passed the station.

The adverbials used in this text indicate temporal progression, and this will be encoded in the DRSs representing the sentences. This means that although CCT applies, its consequent is inconsistent with the rest of the contents of KB. The only rule that applies whose consequent is consistent is Narration, and so $\textit{Narration}(\alpha, \beta)$ is inferred.

Our account of the interaction between tense and adverbials has made crucial use of the fact that we can represent temporal information in two places: in the DRSs, and in the discourse relations. On the one hand, because of the way DRSs are constructed, we achieved equivalence between (16) and (17). On the other, because of the discourse role of the pluperfect as represented in CCT, we explained why (5a,b,c) is coherent but (5a,b,d) is not.

8 Pluperfect Text Segments

We now consider how a pluperfect clause attaches to other pluperfect clauses. Consider text (7); the logical forms of the sentences are respectively α to ϵ.

(7) a. Alex was a very good girl by the time she went to bed yesterday. α

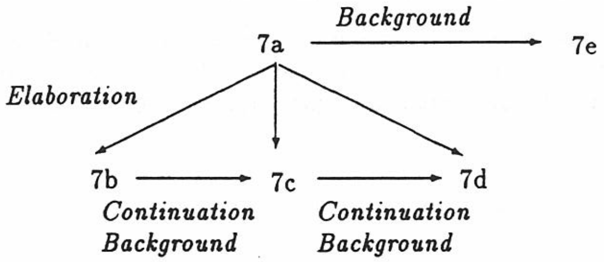
b. She had helped her mum with the housework. β

c. She had practised her piano. γ

d. She had done all her homework. δ

e. We all felt very good about it. ϵ

One infers *Elaboration* between α and each of the pluperfect clauses β, γ and δ using a similar strategy to that outlined in the analysis of (2). We now examine in detail how the pluperfect clauses are related to each other: β is an open clause to γ, and the rules States Overlap, Narration and Continuation apply when attempting to attach them together (Continuation applies because *Elaboration*(α, β) entails $\alpha \Downarrow \beta$). States Overlap and Narration conflict. By the Cascaded Penguin Principle, we infer *Background*(β, γ), and the consequent states these clauses describe overlap. Moreover, we infer *Continuation*(β, γ).[7] A similar line of reasoning applies when attaching δ to the open γ, and so we infer *Background* and *Continuation* to relate these clauses as well. Finally, further pragmatic knowledge that is encoded in DICE form a Nixon Diamond when attempting to attach ϵ to δ, thus inducing a discourse pop to α (we omit details here). Thus the discourse structure of (7) can be pictorially represented as follows:



All we have inferred for (7b-d) is that the consequent states overlap; this doesn't determine the relative starts of these states. So the *events* described in the pluperfect clauses remain unordered, in agreement with intuitions. A more specific rule than States Ovlerap, if conflicting with it, may induce orderings among the pluperfect clauses. In the analysis of (3), we assume there are more specific rules than States Overlap, that convey (a) the pragmatic effects of list-type discourse structures; and (b) knowledge concerning the normal course of events when climbing a mountain.

(3) a. Max arrived at the summit at midday.

b. He had got up at 5:30am,

c. had prepared his lunch,

d. had chosen his route, and

e. had passed base camp before 7am.

By the Penguin Principle, these laws deem States Overlap irrelevant, and so we will infer *Narration*, rather than *Background*, between the pluperfect clauses in (3). *Narration* imposes precedence relations between the consequent states, and so the textual order of the *events* matches their temporal order. Thus DICE provides the means to fulfil the Interaction Desideratum: different pragmatic knowledge yields different temporal structures.

9 Elaboration, Roles and Informativeness

We have seen already with (10) how informativeness plays a crucial role in constraining discourse structure. We now show how the Information Desideratum can be fulfilled in DICE, in order to explain the incoherence of (14).

[7] Again, the predicates are sufficiently independent that we can divide up the nonmonotonic reasoning in this way.

(14) a. John walked over towards Alice and whispered something in her ear.

b. ?He had reached her.

We concentrate here on encoding a Be Informative Constraint on *Elaborations*. We assume that an elaborating segment identifies a *role* of the elaborated segment's event type, where the potential roles must be supplied by the lexicon (cf. Kamp and Rossdeutscher 1992, McRoy 1992). Giving details of the lexical processing that underlies role identification is beyond the scope of this paper. There are several candidate frameworks for lexical semantics that address the relevant issues (e.g., Pustejovsky 1991, Dowty 1989, McRoy 1992). But here, we only encode the *interaction* between the information gained from the lexicon and information at the level of discourse processing.

Elaboration states that if β identifies a role in α then normally, β elaborates α.

- **Elaboration:** $\langle \tau, \alpha, \beta \rangle \wedge \beta$ identifies a role in $\alpha > Elaboration(\alpha, \beta)$

Having inferred role identification through lexical processing, we can use Elaboration to infer the consequences of this at the discourse level.

We encode the Be Informative Constraint for elaborations in terms of a constraint on role identification. In words, it captures the following: β can normally fill a role only if it portrays new information (i.e., β doesn't follow by default from the preceding discourse):

- **Constraint on Role Identification** (CRI): $(\alpha > \beta) > \neg(\beta$ identifies a role in $\alpha)$

This law affects the ability to infer *Elaboration*, because if β doesn't portray new information, then it will normally block the antecedent of Elaboration from being verified.

Consider the consequences of CRI: The clauses in (14a) are represented by α_1 and α_2 respectively.

(α_1) $[e_1, t_1][walk\text{-}towards(e_1), hold(e_1, t_1), t_1 \prec now]$

(α_2) $[e_2, t_2][whisper(e_2), hold(e_2, t_2), t_2 \prec now]$

Attaching α_1 to α_2 using the traditional DRS construction rules fails to supply any temporal relations between the events. We assume that under these circumstances, the default assumption that discourse attachment happens at the sentence-level is violated, and instead one attempts to attach the two *clauses* together, to build an SDRS representing (14a) which imposes temporal structure. Therefore, $\langle \alpha_1, \alpha_1, \alpha_2 \rangle$ is added to the KB. The only rule that applies is Narration, and by Defeasible Modus Ponens, the logical form α of (14a) is $\{\{\alpha_1, \alpha_2\}, \{Narration(\alpha_1, \alpha_2)\}\}$. The logical form of (14b) is β.

(β) $[e_3, t_3][reach(e_3), hold(e_3, t_3), t_3 \prec now]$

Now the task is to attach β to the α. Intuitively, the following world knowledge holds: if someone walks towards somebody and then whispers something in his ear, then normally he must have reached him sometime inbetween. This knowledge is captured in the following law:[8]

- **Reach Law:** $\alpha > (\exists e_3)(reach(e_3) \wedge e_{\alpha_1} \prec e_3 \prec e_{\alpha_2})$

The consequent of the Reach Law entails β. And CE supports Closure on the Right:

[8] We have introduced existential quantification over events, but only in the consequents of rules, so the language is still not full first order.

- **Closure on the Right:** $\phi > \psi, \psi \rightarrow \chi \models \phi > \chi$

Thus from the Reach Law we can infer that $\alpha > \beta$. This has an impact on the way β attaches to α. The KB verifies the antecedents to CRI, States Overlap, Narration and CCT. The line of reasoning can be divided up in the logic as follows: as before $overlap(e_\alpha, e_\beta)$ and $C_{pp}(\alpha, \beta)$ are inferred via the Penguin Principle. We also infer that β doesn't identify a role in α via CRI. Because of this, we are unable to infer that β elaborates α, because Elaboration doesn't apply. Indeed, there is not sufficient knowledge in the reader's KB to infer any of the discourse relations permitted by C_{pp}, and this leads to incoherence.

10 The Pluperfect and Perspective

We have exploited the interaction between lexical and discourse processing to encode how the information status of clauses affects coherence. We will exploit this interaction further, in order to analyse the perspective shift that occurs in free indirect style (FIS) as illustrated in text (12).

(12)	a.	The telephone rang:	α
	b.	It was Mme Dupont;	β
	c.	Her husband had eaten too many oysters.	γ
	d.	The doctor recommended a change in lifestyle.	δ

The analysis of (12) proceeds as follows: let the logical forms of the sentences be respectively α to δ. First we consider the lexical information in α. Pustejovsky's (1991) representation of lexical entries for artefacts includes a representation of their telic roles. We assume that the telic role of a telephone is to have a conversation. This telic role invokes three roles, identified below by x (the speaker), p (the thing that's said) and y (the listener).

- **From the Lexicon:** $telephone > x$ said that p to y

This lexical information influences discourse attachment: upon attempting to attach β to α, the reader infers that Mme Dupont can fill the role x, and so by default, she does. Having identified Mme Dupont as filling this role, Elaboration applies. By the Penguin Principle on Narration and Elaboration, $Elaboration(\alpha, \beta)$ is inferred.

Now the task is to update this SDRS with γ; α and β are both open clauses. Caenepeel (1989) argues that if the discourse context induces a psychological perspective of a protagonist x, and the clause currently being processed is a stative, then that current clause is interpreted with respect to x's point of view. In this example, the context provided by α does induce a psychological perspective because the above telic role invokes the propositional attitude *said that*. Furthermore, γ is in the pluperfect, and therefore is stative. This motivates Caenepeel's Axiom below: it states that a pluperfect sentence γ by default identifies the proposition p in the propositional attitude context ψ invoked by α.

- **Caenepeel's Axiom:** $\langle \tau, \alpha, \gamma \rangle \wedge pp(\gamma) \wedge \psi(\alpha, p) > \gamma$ identifies p

Now consider the reasoning behind attaching γ to the preceding open clause α. The rules that apply are Narration, States Overlap, CCT and Caenepeel's Axiom. Nothing in the reader's KB conflicts with the consequent of Caenepeel's Axiom, and so its consequent is inferred; i.e., γ identifies p. Now Elaboration applies, and whilst conflicting with Narration, it's more specific and

$$\begin{array}{|l|}\hline e,t,x,p,s_0,t_0 \\ \hline hold(e,t) \\ t \prec now \\ ring(telephone,e) \\ say(x,p,s_0) \\ hold(s_0,t_0) \\ \hline \end{array}$$

$\Downarrow$ Elaboration

$$\begin{array}{|l|}\hline \\ \hline \begin{array}{|l|}\hline d \\ \hline d = x \\ \hline \end{array} \quad p \subseteq \begin{array}{|l|}\hline \\ \hline \begin{array}{|l|}\hline w,s,t' \\ \hline husband(w,d) \\ s : \begin{array}{|l|}\hline e \\ \hline cs(e) = s \\ eat\text{-}too\text{-}many\text{-}oysters(w,e) \\ \hline \end{array} \\ hold(s,t') \\ t' \prec now \\ t' \preceq t_0 \\ \hline \end{array} \\ \hline \end{array} \\ \hline \end{array}$$

Figure 1: The SDRS representing The Telephone Text

Elaboration(α, β) is inferred. In attaching γ to β, Continuation fires and *Continuation*(β, γ) is inferred.

The full representation of (12) is given in Figure 1. The telic role for *telephone* has been identified, and so *say*(x, p, s_0) is added to the DRS representing α. β and γ's DRS conditions then identify the roles: $d = x$ in β (i.e., Mme Dupont is the speaker on the phone), and $p \subseteq \gamma$ in γ (i.e., what was said over the phone is denoted by γ). So, α contains a *propositional attitude* of *saying*, which given the other DRSs, holds between Mme Dupont and the proposition denoted by γ.[9] Thus the representation of (12) encodes the perspective shift that occurs when interpreting γ. And note that elaborations can actually affect the truth conditions of DRSs by specifying arguments of event types: in this case, recognising the elaboration enabled $d = x$ and $p \subseteq \gamma$ to be added to the DRS conditions.

11 Conclusion

In this paper, we have examined how the pluperfect tense affects the temporal structure and rhetorical structure of narrative text. We have argued that contrary to the Reichenbachian approach, the discourse role of the pluperfect must take the reader's background knowledge into account. We have provided an analysis in which the pluperfect is viewed as a syntactic discourse marker, which indicates that only a restricted set of discourse relations are permitted in order to attach the current clause to the preceding text. In order to capture the correct interaction between the simple past, pluperfect and temporal connectives, we viewed the simple past and pluperfect as *sententially* equivalent, although they play distinct discourse roles because of the different constraints they impose on coherent discourse.

When attaching a pluperfect sentence to a simple past tensed one, the task is to infer which of the four discourse relations *Explanation*, *Elaboration*, *Parallel* or *Contrast* hold. Information obtained from the lexicon can be used to do this. For example, the lexicon provides potential thematic roles which the pluperfect clause can identify; if it does, then this results in an *Elaboration* at the discourse level. In this sense, the pluperfect provides a forum in which to explore how information at the lexical level interacts with information at the discourse level. This feature of the analysis is exploited in two ways in this paper. First, we used a mixture of lexical and discourse information to capture the constraint *be informative* on coherent discourse. Second, the shift in perspective that can be triggered by the pluperfect was characterised by a combination of role identifications gained from the lexicon, and Caenepeel's Axiom, which is a pragmatic rule concerning discourse attachment.

Several questions remain unanswered. Analysing the pluperfect requires an integrated account of lexical and discourse processing. But this is beyond the scope of this paper. Further research must be pursued in lexical semantics, that addresses the problem of how rhetorical information influences lexical processing. Likewise, the theory of discourse attachment must be augmented with a detailed account of how informations flow from the lexicon to the textual level.

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The Temporal Structure of French Texts within Segmented Discourse Representation Theory

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Recent work has shown that accounts that exploit only compositional rules for the treatment of tenses and adverbs in English do not give a very satisfactory picture of the temporal order of a text. The most sophisticated theories of this kind have evolved from Reichenbach's anaphoric treatment of tense, of which the analyses in Discourse Representation Theory are the most sophisticated versions (Kamp and Rohrer 1983, Eberle and Kasper 1989). Most of the efforts in DRT have been directed at the analysis of French tense. The system of French tense was thought to be more amenable to a compositional semantic treatment than English. In this paper we show that the difficulties that afflict a purely compositional semantic account of English tense also afflict accounts of French. We use the formal discourse framework proposed in (Lascarides and Asher 1991) and (Asher 1993) to model human comprehension of time in text and to give an alternative account of the semantic contribution of tense to the temporal structure of a text.

1. Classical DRT and French Discourses in Passé Simple (PS), Imparfait (IMP) and Plus-Que-Parfait (PQP)

The original DRS construction rules predict that if a sequence of sentences in the PS follow each other in the text, then the events are ordered in time as they are introduced in the text. But examples have been pointed out (Kamp and Rohrer 1983, 1985, Bras 1990a) to show that temporal order does not always match textual order :

(1) L'année dernière Jean escalada le Cervin (e1). Le premier jour, il monta jusqu'à la cabane (e2). Il y passa la nuit (e3). Ensuite, il attaqua la face Nord (e4). Douze heures plus tard il arriva au sommet (e5).

(2) L'avion alla jusqu'à Toulouse (e1). Il survola les Pyrénées (e2).

(2.a) L'avion quitta Madrid (e0). Il alla jusqu'à Toulouse (e1). Il survola les Pyrénées (e2).

(2.b) L'avion quitta Paris(e0). Il alla jusqu'à Toulouse (e1). Il survola les Pyrénées (e2). Puis il atteignit Madrid (e3).

(2.c) L'avion quitta Madrid (e0). Il alla jusqu'à Toulouse (e1). Puis, il survola les Pyrénées (e2).

(3) L'été de cette année-là vit plusieurs changements dans la vie de nos héros (e1). François épousa Adèle (e2). Jean-Louis partit pour le Brésil (e3) et Paul s'acheta une maison à la campagne (e4).

In (1), e2, e3, e4 et e5 can be considered as subevents of e1. They elaborate the description of e1, and each of them stands in an inclusion relation to e1. (3) illustrates also this event/subevent relation but here, the temporal order of the subevents mismatches their textual order. For (2), we cannot predict the relation that holds between e1 and e2 without further information. In (2.a) and (2.b), geographic knowledge provides information to determine the relation between e1 and e2. For (2.a), we infer e2 $\subseteq$ e1, for (2.b) we infer e1 < e2. In (2.c), we also have e1 < e2 but this is predicted thanks to the semantics of the adverb *puis.*

When a sentence in the IMP follows a sentence in the PS, the construction rules predict that the state introduced by the second sentence overlaps the event introduced by the first one as in (4).

(4) Jean entra dans le salon. Marie pleurait.

The IMP rule also has counter-examples (Hinrichs):

(5) Pierre éteignit la lumière (e1). Il faisait nuit noire (s2) car les volets étaient fermés.

(6) Marie arriva en retard au cinéma (e1). Elle attendait son mari à la maison (s2).

In (5), there is a causal link between e1 and s2, which is incompatible with the temporal relation of inclusion predicted by the rule. For (6), the prediction that s2 overlaps e1 is wrong too.

Refining the Reichenbach analysis, the PQP is analysed in DRT as introducing an event in the past of a perspective point (Kamp and Rohrer 1983). The construction rules for the PQP deal with temporal flashbacks, as illustrated in (7), where the event e2 goes back in time with respect to the perspective point e1 introduced by the first sentence. Then the flashback is continued by the events e3, e4, e5 and e6.

(7) A midi, Jean arriva au sommet du Vignemale (e1). Il était parti du refuge des Oulettes au lever du jour (e2). Il avait passé la Hourquette d'Ossoue vers 8 heures (e3). Deux heures plus tard, il avait atteint le glacier (e4). Il s'était engagé dans le couloir vers 11 heures (e5). Une heure plus tard il avait fini (e6). Du haut du Vignemale, il contempla un panorama extraordinaire (e7).

But the textual order of the flashback events does not always match their temporal order, as illustrated in (8).

(8) Hier soir, Papa a félicité Alexia (e1). Elle avait fait ses devoirs (e2). Elle avait aidé sa maman à préparer le repas (e3). Elle avait révisé sa leçon de piano (e4).

In the sequence of PQP sentences, a PQP sentence can introduce a flashback event of the previous PQP sentence (and not of the PS sentence), as event e4 in (9). Here again the temporal order of the PQP sentence events mismatches their textual order.

(9) A midi, Jean arriva au sommet du Vignemale (e1). Il était parti du refuge des Oulettes au lever du jour (e2). Il avait passé la Hourquette d'Ossoue vers 8 heures (e3). Il avait marché très vite pour atteindre le col (e4)....

Lastly, the flashback is not the only scenario. When a sequence of sentences in the PQP follows a sentence in the PS, the PQP sentences can also introduce subevents of the first sentence event, as in (10).

(10) Ce jour-là, Jean escalada le Vignemale (e1). Il était parti du refuge des Oulettes au lever du jour (e2). Il avait passé la Hourquette d'Ossoue vers 8 heures (e3) Deux heures plus tard, il avait atteint le glacier (e4). Il s'était engagé dans le couloir vers 11 heures (e5). A midi, il était au sommet (s6).

2. The Basic Framework for the Analysis of Discourse Structure and Temporal Order

The preceding examples show that aspect and tense information is not the only one to determine temporal relations between the temporal referents of a discourse. At best, a DRT account of tense will deal with sequences of sentences in the PS, as Eberle suggested (Eberle 1988, Eberle & Kasper 1989), by introducing an indeterminate relation not-before (intuitively $e1 < e2$ or $e2 \subseteq e1$). But with the PQP sequences, even this relation will not do. Lascarides and Asher defend the thesis that the entire mechanism of Reichenbachian temporal reference points, refined in the work in DRT, may be dispensed with in an analysis of tense that exploits discourse structure and discourse information. Their work, however, covers only a small fragment of English. Below we sketch the barest minimum of this framework as we have adapted it to the analysis of French tense and temporal adverbs.

Asher (1993) presents a theory of discourse structure, *Segmented Discourse Representation Theory* or *SDRT*, which serves as the framework for our analysis. The basic building blocks of discourse structure are propositions with a dynamic content, which we will represent as DRSs. However, constituents of a discourse structure may be more complex and must be defined recursively. In SDRT, a natural language text is represented by a SDRS, which is a pair of sets containing : the SDRS or DRSs representing respectively text segments or sentences, and discourse relations between them.

These structures are constructed in a dynamic fashion like DRSs. The basic constituents are derived from single sentences (this is a simplification but will serve to analyze the texts we have presented above). To build an SDRS for a text, we proceed sentence by sentence, adding the DRS derived from each sentence to the structure until there are no more to be analyzed. Since an SDRS unlike a DRS is a structured object, information derived from sentence S_{n+1} may be added at several points to the SDRS constructed from $S_1, \ldots, S_n$. The problem of what constitutes an acceptable attachment point is discussed in Asher (1993); here we will assume that these are given. The principal difficulty then in defining a discourse structure for a text, and hence its associated temporal order, involves the discovery of discourse relations modelled after those proposed by Hobbs (1985), Mann and Thompson (1987) link together the constituents of an SDRS. We will use eight discourse relations: Narration, Elaboration, Explanation, Background, Precondition, Continuation, Parallel and Contrast. The first five of these constrain temporal structure: Narration entails that the descriptive order of events matches their temporal order; an Elaboration, Precondition or Explanation entails that they mismatch; Background entails temporal overlap.

Certain discourse relations in an SDRS impose a hierarchical structure; these subordinating relations are Elaboration and Explanation. The so-called *open* constituents to which new information can attach are the previous constituent or constituents it elaborates or explains. Thus the open clauses are those on the right frontier of the discourse structure (Polanyi 1985, Grosz and Sidner 1986, Webber 1991), assuming that it is built in a depth first left to right manner.

Discourse relations between constituents are inferred in a nonmonotonic logic of Asher and Morreau (1991). The language of this logic is that of first order logic augmented with a nonmonotonic conditional operator, >. Lascarides and Asher (1991, 1993) develop a theory about discourse relations which they call DICE. DICE contains axioms in which discourse relations are inferred by default. They often combine world-knowledge with the contextual information that a particular attachment affords. DICE makes the following claims. First, the logical form of a sentence does not encode movement of time through discourse. Instead, the current sentence is attached to the preceding discourse structure with a discourse relation; the process by which this is done takes the reader's background knowledge into account, and the resulting discourse structure determines how time moves through discourse. So, in contrast to Eberle and Kasper (1989, 1991), temporal structure is directly affected by the reader's knowledge. Here, we assume the reader's KB contains: the logical forms of the sentences; an assumption that the current sentence must attach at an open site (i.e., the text is coherent); all defeasible and indefeasible world and pragmatic knowledge; and the laws of logic.

3. Analysis of Examples

We have verified that DICE handles all the cases that the classical analysis is able to treat. Below we show the additional power of the discourse approach. In example (2.a), a difficult case of a text in the PS treated by the classical analysis, we take over a DICE axiom for English. Below, $<\tau, \alpha, \beta>$ means that β is attached to α in the SDRS τ:

(A1) $<\tau, \alpha, \beta> \ > \ \text{Narration}(\alpha, \beta)$.

Now we process (2.a). First, we derive k_1 from the first sentence. In order for the text to be coherent, we must attach k_2, derived from the second sentence, to k_1. Both main verbs are in the PS, and no other axiom that might conflict with the inference of Narration intrudes in this case; so we conclude by default, Narration(k_1, k_2). Since Narration determines a temporal order in DICE by means of the axiom (A2),

(A2) $\Box\,(\text{Narration}(\alpha, \beta) \rightarrow e_\alpha < e_\beta)$

we have that the event described in k_1 (there is only one) must precede the event in k_2. Now we get k_3, which we assume must be attached to k_2. Axioms about the location of objects in Narrations tell us that the plane goes from Madrid to Toulouse in the voyage described in k_2. By world knowledge we know that crossing the Pyrenees is part of the voyage of going to Toulouse from Madrid. So we have in the KB the axiom:

(A3) $\forall e\,(\text{aller-de-Madrid-à-Toulouse}(e) > \exists e'\,(\text{survoler-les-Pyrénées}(e')\ \&\ e' \subseteq e))$

Now this of course does not in and of itself prevent Narration(k_2, k_3), since it could be that the event in k_3 is another overflight of the Pyrénées (cf example 2.c). But in DICE, there is a general axiom about Elaborations:

(A4) $(<\tau, \alpha, \beta>\ \&\ e_\alpha \subset e_\beta) > \text{Elaboration}(\alpha, \beta)$

Notice that the antecedent of (A4) entails the antecedent of (A1). (A4) and (A1) conflict because Elaboration is a discourse relation which in DICE gives a temporal ordering incompatible with that given by Narration.

(A5) $\square$ (Elaboration(α, β) $\rightarrow$ $e_\beta \subseteq e_\alpha$)

Because the underlying logic of DICE forces us to take the conclusion of the more specific law, we get Elaboration(k_2, k_3). By the meaning of Elaboration, we get as desired: $e_\beta \subseteq e_\beta$ Interestingly, the PS in French is more restrictive than the English simple past. We find that unlike the simple past, sequences of sentences in PS in French generate constituents that admit happily of only two discourse relations--Elaboration and Narration. On the other hand, sequences of simple past sentences in English also allow for temporal reversals and relations like Explanation.

We now treat one example from the IMP. Below, PS() (resp. IMP()) is a predicate on constituents that stands for the fact that the main verb of the sentence from which the constituent was derived is in the PS (resp. in the IMP). The basic axiom for the use of IMP following PS is Background. Thus, in DICE:

(A6) (PS(α) & IMP(β) & $\langle\tau, \alpha, \beta\rangle$) > Background($\alpha$, β)

(A7) $\square$(Background(α, β) $\rightarrow$ $e_\alpha \subseteq e_\beta$)

In example (5), we derive, however, from the combination of world knowledge and information about the discourse context, the law (T10):

(A8) (PS(α) & IMP(β) & $\langle\tau, \alpha, \beta\rangle$ & (β describes a possible result of α))
> Result(α, β)

(A9) $\square$((éteindre-la-lumière(α) & faire-nuit-noire(β) & $\langle\tau, \alpha, \beta\rangle$)
$\rightarrow$ (β describes a possible result of α))

(T10) (PS(α) & IMP(β) & éteindre-la-lumière(α)& faire-nuit-noire(β) &$\langle\tau, \alpha, \beta\rangle$) > Result($\alpha$, β)

Using (T10), (A9), the information contained in example (5), and the inference mechanisms of DICE, we again infer Result(α, β) for (5). The relation of Result imposes a strict temporal relation between the eventualities of the constituents it relates :

$$(A10)\ \Box\ (\ \text{Result}(\alpha, \beta) \rightarrow e_\alpha < e_\beta\ )$$

We thus obtain for (5) :

$$e1 < s2$$

Once again we have found that in French, a change in the sequence of tense from the PS to the IMP restricts the discourse relations, though less so than with the sequence of verbs in the PS. The change of tense discourse rule in DICE is:

$$(A11)\ (\text{PS}(\alpha)\ \&\ \text{IMP}(\beta)\ \&\ \langle\tau, \alpha, \beta\rangle) \rightarrow \neg\text{Narration}(\alpha, \beta).$$

Finally, we examine the case of the use of the PQP. The switch from PS to PQP also has a discourse function. Again Narration is precluded:

$$(A12)\ \Box\ (\text{PS}(\alpha)\ \&\ \text{PQP}(\beta)\ \&\ \langle\tau, \alpha, \beta\rangle) \rightarrow \neg\text{Narration}(\alpha, \beta)$$

The standard flashback example (7) yields an instance of Precondition, on which the constituent derived from the sentence with the PQP describes an event in a path leading up to *source(e_α)*, the location of e_α at the beginning of the event. Precondition like elaboration is a subordination relation. To establish this relation, we use the additional information that the climb to the summit implies the existence of a trajectory to the top. This information is made available by, among other things, the lexical semantics of *arriver*. World knowledge gives us the information that a trajectory going from the refuge des Oulettes to the summit of the Vignemale is a possible trajectory.

$$(A13)\ (\langle\tau, \alpha, \beta\rangle\ \&\ (\alpha \text{ describes a possible precondition of } \beta)) > \text{Precondition}(\alpha, \beta)$$

$$(A14)\ \Box\ (\ \text{Precondition}(\alpha, \beta) \rightarrow e_\beta < e_\alpha\ )$$

Thus, by axioms (A13)-(A14) and the world knowledge alluded to earlier:

$$e2 < e1$$

The real difficulty for the analysis of the PQP concerns sequences of verbs in PQP. In the absence of more specific information, one would apply axiom (A1) and obtain by defaut:

Narration (k2 , k3)

However, this would fail to predict the temporally unordered events introduced by the clauses in the pluperfect of story (8). The event of Alexia practicing the piano could precede that of her doing her homework without falsifying (8). So the basic discourse law for sequences of PQP is the following :

(A15) (PQP(α) & PQP(β) & <τ, α, β>) > Continuation(α, β)

But the presence of adverbs, whose treatment in SCARTT (Bras 1990a) we incorporate in DICE, may force Narration to hold between constituents. For example in the second two clauses of (7), the information given by the measure adverbials— e.g., *au lever du jour* which describes a temporal zone inwhich the eventuality described by the verb takes place that normally comes before the one that is described by the adverbial *vers huit heures* — force a narrative sequence. The semantics of the temporal reference adverbial (ART) *au lever du jour* is in effect explicitly anaphoric, since it refers to a particular day. Now although there is no day mentioned in k1, we infer that the climb happened on a particular day, and it is this day that is the antecedent of *jour*. Now the adverbial *vers huit heures* is also anaphoric; and it also refers to the time on a particular day. Bras and Molinès (Bras 1990a, Bras & Molinès 1991) call such adverbial phrases directly designative of a time and anaphoric to a larger interval of time (ART-DD-anaphoric); such adverbials designate a portion of a larger temporal span within which the eventuality they modify takes place. We are interested in the anaphorically given larger temporal span. This span must be a day. Given the attachment of k3 to k2, the only day that is available as an anaphoric antecedent is the one mentioned in *au lever du jour* or the one implicitly assumed in k1, which are, as we have already seen the same day. Now we can calculate that if the two adverbials refer to the same day, the eventuality that takes place at dawn comes before the one that takes place around eight. Given these anaphoric attachments we are thus forced to conclude that we have a narrative sequence. The following, somewhat cumbersome DICE axiom summarizes the discourse effect of these adverbials.

(A16) $\Box((\langle\tau, \alpha, \beta\rangle$ & ART-DD-anaphoric(α) & ART-DD-anaphoric(β) & β refers to the same larger temporal span as is given in α & the time directly designated in α < the time directly designated in $\beta) \rightarrow$ Narration(α, β))

So we conclude in virtue of (A16) and (A15) and the inference mechanism of DICE:

Narration(k2, k3)

Axiom (A17) expresses the fact that in a hierarchical structure like that defined by elaboration or precondition, the subordinate constituents are linked to the dominating constituent by the same discourse relation:

(A17) $\Box$ (($\langle\tau$, β, $\gamma\rangle$ & $\alpha\Downarrow\beta$ & $\varphi(\alpha, \beta)$ & (Narration(β, γ) $\vee$ Continuation(β, γ))) $\rightarrow$ $\varphi(\alpha, \gamma)$)

(A17) applies as a coherence constraint for hierarchical structures, of which our treatment of (7) now constitutes an example. But our attachment of k3 to k2 by Narration is coherent, since the knowledge base contains the information that the *Hourquette d'Ossoue* fait is part of a path to the summit of the Vignemale, we deduce that e3 is a possible precondition for e1 (cf. Asher et al 1993). By (A13), assuming an attachment to k1 we then by default deduce :

Precondition (k1, k3)

which coheres with the requirement of (A17). Finally with (A14) and (A2) we deduce:

e2 < e3 et e3 < e1

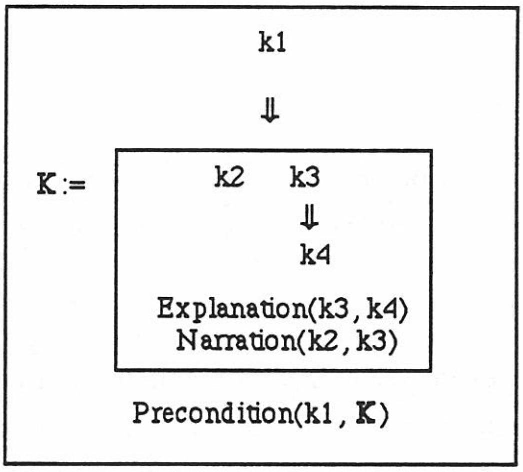
Let us turn now to example (9), in which the first three clauses are identical to those in (7), and let us examine the link between k3 et k4. We represent by an axiom in the lexicon the fact that the word *Hourquette* refers to a pass in the local dialect. The attachment of k4 to k3 in the SDRS for (9) allows us to determine the anaphoric antecedent for *le col* in the fourth sentence. Given <τ, k3, k4>, the discourse referent introduced by *le col* can and must be identified with the discourse referent introduced by *la Hourquette d'Ossoue*. Given the constraints on anaphora resolution and SDRS availability described in (Asher 1993), this is the only attachment on which an appropriate antecedent for the definite description can be found and so the only attachment that preserves the coherence of the discourse. So we must have <τ, k3, k4>.

We must now determine the discourse relation between k4 and k3. The preposition *pour* links the proposition derived from the main clause of the fourth sentence with k3. The discourse effect of *pour*, together with the content of the clauses it relates and the contents of k3 and k4 forces us to conclude Explanation(k3, k4)--Jean got to the pass at the time he did because he walked so quickly. Again what leads us to this conclusion is a mixture of knowledge of the discourse context and world knowledge. The following axiom expresses a principle about what discourse purposes an author would typically use with a particular linguistic form; it says that if we have a constituent that expresses the proposition that some agent did p in order to bring about q and if we assume that α is attached to β in τ and α entails q and β entails p, then we should infer β describes a possible explanation of α. With the following axioms we are able to conclude that there is a relation of explanation between k3 and k4 in DICE.

(A18) $\langle\tau, \alpha, \beta\rangle$ & (β describes a possible explanation of α) > Explanation(α, β)

(A19) $\Box$ (Explanation(α, β) $\rightarrow \neg e_\alpha < e_\beta$)

To this point, we have constructed an SDRS that may be schematically represented like this:



The arrows $\Downarrow$ denote the discourse subordination relation. Constituents above the $\Downarrow$ dominate while those below are subordinate. Let us now look at the attachment points for k5. There are three :

- k4, which is subordinate to k3
- k3
- k1

Let us examine first the link between k3 and k5. As before we would again conclude Continuation(k3, k5), except that the presence of the temporal adverbials force a narrative sequence. k5 contains an anaphoric adverbial phrase *deux heures plus tard*, for which we must find an appropriate temporal antecedent in the discourse context. Further, the adverbial also introduces a relation of temporal posteriority that forces a narrative sequence. *Deux heures plus tard* is a temporal adverbial (ART) that Bras (1990a) and Bras & Molinès (1991) call "*désignation calculée*" : to designate the temporal zone that serves to localize the eventuality modified by the adverbial, it gives a measure, the size of which is given by the nominal *deux heures*, and the direction of the measure on the temporal axis (post) is given by *plus tard*. In DICE the following axiom represents the semantics and discourse effects of such adverbials :

(A20) $\Box$ ($<\tau, \alpha, \beta>$ & ART-DC-anaphorique-post(β) $\rightarrow$ Narration(α, β))

The situation in which we find ourselves with k3 and k5 is now exactly like that with k2 and k3. As before using the axioms for precondition, continuation and exploiting the content of the adverbials with (A20), we deduce :

Narration(k3, k5)

This seems perfectly reasonable.

Let us now see whether any other attachments of k5 are possible. Let us consider $<\tau$, k4, k5$>$. By the content of the adverbial in k5, we are forced to deduce :

Narration(k4, k5)

Axiom (A17), which assures the coherence of hierarchical structures, implies that if we have Narration(k4, k5), then we must have Explanation(k3,k5). But this is problematic, since this is supported neither by world knowledge nor by the discourse context. Thus, this attachment saddles us with a discourse relation that is not supported by the text and this forces an incoherent discourse structure. In order to preserve coherence, then, we must exclude the attachment of k5 to k4. The only other possible attachment point is (k1), but axiom (A12) forbids narration, while the axiom based on the content of the adverbials (A20) requires it. This attachment is thus impossible, since there is no discourse relation that can be consistently inferred given $<\tau$, k1, k5$>$. Thus, the only possible attachment point is k3, and we have Narration(k3, k5) and Precondition(k1, k5). With (A2), (A17) and (A14), we deduce the following temporal relations:

$e3 < e5$ et $e5 < e1$

A similar story goes for k6. We deduce :

Precondition(k1,k6) and Narration(k5, k6)

Finally, we turn our attention to the seventh clause in (7). We derive k7 from a clause in the PS. A change of tense, a fortiori in the case of a change from the PQP to PS, introduces a break in the discourse relation in French, as axiom (21) shows :

(A21) $\Box$ ($<\tau, \alpha, \beta>$ & PQP(α) & PS (β) & R(γ, α)) $\rightarrow \neg$R(γ, β)

Now we cannot attach k7 to k6 by narration, since (A17) requires Precondition(k1, k7) et (A19) forbids it. Given (A21), k1 is the only attachment point, and one obtains by axiom (A1) :

Narration(k1,k7)

and by A2:

$e1 < e7$

In the analysis of the PQP in French, we have seen that SDRT allows us to treat the classic flashback case (discours (7)), as well as the more complex example (9) in which within the sequence of clauses in the PQP, we find not only propositions related by narration but also by explanation. Discourse (8) is a nice example where we have no narrative sequence at all with a sequence of clauses in the PQP. By the axioms for explanation, world knowledge and knowledge of the discourse context, we get:

Explanation(k1, k2)

Since there are no temporal adverbials to force narration in this case, we have by default from axiom (A15) and from $<\tau, k2, k3>$ and $<\tau, k3, k4>$:

Continuation(k2, k3) and Continuation(k3, k4)

Continuation imposes no temporal constraints on the eventualities in the constituents it relates; it implies simply that k3 and k4 "continue" the discourse function of their attachment point, as is made explicit by (A17). But since k3 and k4 also serve to explain k1 (why Alexia's Dad complimented her), we have a coherent discourse given <τ, k2, k3> and <τ, k3, k4>. Since we have Explanation(k1, k2), we deduce form (A17):

Explanation(k1, k3) and Explanation(k1, k4)

Since continuation imposes no temporal constraints: k2, k3 et k4 are not temporally ordered with respect to each other--a prediction which accords with intuition.

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Linguistic information and world knowledge in temporal reasoning

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0. Introduction

The question I will deal with in this paper is whether linguistic information conveyed by the sentences of a (narrative) discourse is sufficient to make inferences about the temporal relations between the eventualities the discourse is about.
Proposals for the interpretation of temporal relations by Kamp, Kamp & Rohrer, Hinrichs, Dowty, Partee, suggest that the answer is positive. At least their rules do not take into account world knowledge. In recent proposals by Alex Lascarides, Jon Oberlander and Nicholas Asher, the answer to this question is 'no, it is not'. They propose rules which make use of world knowledge as we will see (section 2).

My own position in this debate is that I do not deny that world knowledge does play an important role in text understanding, but that it is worthwile to exploit as much as possible the linguistic information. In this paper I will consider one of the sources of linguistic information, namely the lexico-semantic properties of the verbs used in the sentence (Aktionsart). It will be shown that they are able to provide important clues for discourse interpretation.

The structure of the paper is as follows.I will first briefly recapitulate the main rules which have been proposed in the 'linguistics-only' approaches, then discuss the kind of rules proposed by Lascarides c.s. After a look at the classification of eventualities, I will propose lexical entries for verbs, which are able to handle the 'difficult' cases mentioned by Lascarides et al.

1. The 'linguistics only' approach

In this section I will recapitulate the most influential proposals for the interpreation of temporal discourse relations:

a. Hinrichs(1981); Partee (1984):

Simple Past + Non-Durative Aktionsart: event

Simple Past + Durative Aktionsart: state

(i) if a sentences introduces an event, it is attached to the current reference point and at the same time a new reference point is introduced which follows immediately the former one:

```
       r1   r2
  -----0---------------------
       e1
```

(ii) If a second event (e_2) is introduced) this gives rise to the following configuration:

```
       r1   r2  r3
  -----0----0------------------
       e1   e2
```

(iii) If the following sentence introduces a state (s_1), it is attached to the current reference point (r_2), but no new reference point is created:

```
       r1   r2
  -----0----0-----------------
       e1   s1
```

b. Dowty (1986)
Any sentence in the SP introduces a 'new' reference point, irrespective of the Aktionsart of the sentence (cf. ii, under a).

c. Kamp (1981) (for French):

Passé Simple (henceforth PS): event

Imparfait (henceforth IMP): state

(i) event + event:

```
  ---0----0-----------
     e1   e2
```

(ii) event + state:

```
  ---0-----------------
     e1
   \____/
     s1   (overlap)
```

Kamp and Hinrichs regard states as 'anaphoric' elements, which have to be related to some antecedent which is already present in the discourse domain.

2. Lascarides, Oberlander & Asher

In several recent papers, these authors observe that there are sentences in English which have exactly the same syntactic form, but which have to be assigned different interpretations. Consider, for example, the following pairs:

(1) a. Max stood up (e_1). John greeted him (e_2).
   (Narration: $e_1 < e_2$)
 b. Max fell (e_1). John pushed him (e_2).
   (Explanation: $e_2 < e_1$)

(2) a. Max opened the door (e_1). The room was pitch dark (e_2).
   (Background: overlap (e_1, e_2)
 b. Max switched off the light (e_1). The room was pitch dark (e_2). (Cause ,Switch Off Causal Law: $e_1 < e_2$)

(3) a. Max took an aspirin (e_1). He was sick (e_2).
   (Explanation: $e_2 \leq e_1$)
 b. Max took an overdose of aspirin (e_1). He was sick (e_2).
   (Cause: $e_1 < e_2$)

Fragments such as (1a), which constitute the default case, are handled by the rules for Narration of (4):

(4) a. Narration <δ, α, ß> > Narration (α,ß)
 b. Axiom of Narration: Narration (α,ß) -> $e_\alpha < e_ß$
   Where '>' stands for the defeasible implication (if... then normally) and '->' for the indefeasible implication.

Fragment (2a) is interpreted with the help of rules (5a,b):

(5) a. Background: <δ, α, ß> & overlap (e_α, $e_ß$) > Background (α, ß)
 b. Axiom of Background: Background (α, ß) -> overlap (e_α, $e_ß$)

In fact (4) and (5) correspond with Hinrich's rules (cf. section 1).

Lascarides et al. claim that for (1b), (2b) and (3a,b) different rules are needed, which make explicitly use of world knowledge. Rule (6), is, for example, capable of accounting for the 'anomalous' order of the events in (1b). It states that a pushing event may cause a falling event:

(6) a. Push Causal Law: <δ, α, ß> & fall (max, e_α) & push (john, $e_ß$) > cause ($e_ß$, e_α)
 b. Causes Precede Effects: Cause (e_2, e_1) -> $\neg$ $e_1 < e_2$

Where '<' stands for 'anterior to'.

Analogous rules handle the other irregular cases.

In this paper I will be particularly interested in example (1b). But first will have a look at some general features of text cohesion that play a role in the interpretation of discourse.

3. Text cohesion.

Anaphoric relations between the elements of a discourse contribute in an important way to its cohesion. It is not surprising then that Kamp, Hinrichs and Partee formulate the relationship between events and states in terms of anaphor. The stative sentences are anaphoric because the state they refer to has to be related to some temporal antecedent (an event, for example). However, anaphoric relations show a great variety. The most common type of anaphor, that between a pronoun and its antecedent cannot be taken as a model for the relationship between events and states. Pronouns are generally coreferential with their antecedent, whereas complete temporal coincidence of states and events is rather exceptional. Compare:

(7) a. Peter went to the bookshop

b. He bought a novel by Bernard Malamud

(8) a. Jeanne descendit (PS) l'escalier (e_1)

'Jeanne descended the stairs'

b. Elle souriait (IMP) (s_1)

'She was smiling'

In (7b) the pronoun he is coreferential with Peter, while the temporal relation between the s_1 and e_1 of (8) is more complex. In purely temporal terms s_1 overlaps with e_1, but s_1 need not occupy exactly the same interval (s_1 may have started before e_1 and end after it). Another difference is that he in (7b) does not provide supplementary information about Peter, whereas the IMP sentence of (8b) gives information about one of the aspects of the event e_1, here the manner in which Jeanne descended the stairs. The relationship between (8a) and (8b) resembles more that between the house and the roof in:

(9) a. I bought a house last week.

b. The roof has to be repaired

The roof is part of the house, in roughly the same way as in (8) Jeanne's smiling is a part of her descending of the stairs.

Moreover, the indefinite article of the NP a house and the PS of (8a) have both the function to introduce a new referent into the discourse domain (respectively, an individual pertaining to the set of the houses and an event of the type Jeanne descendre l'escalier). The definite article and the IMP have in common that they indicate that the entities referred to by respectively the NP and the sentence have to be related in one way or another to some previously introduced element. But this comparison falls short because it is the PS rather than the IMP that is used to refer to part/whole relationship between events:

(10) a. L'année dernière Jean escalada (PS) le Cervin. (e_1)
'Last year Jean climbed the Cervin'
b. Le premier jour il monta (PS) jusqu'à la cabane H. (e_2)
'The first day he climbed to hut H.'
c. Il y passa (PS) la nuit (e_3)
'He spent the night in it'
d. Ensuite il attaqua (PS) la face nord (e_4)
'Then he mounted the northern slope'
e. Douze heures plus tard il arriva au sommet (e_5)
'Twelve hours later he arrived at the summit'
(Kamp & Rohrer, 1983)

The PS is also used to enumerate the elements of a previously introduced set of events:

(11) a. Cette année-là vit (PS) plusieurs changements dans la vie de mes héros. (e_1)
'That year saw several changes in the lives of my heroes.'
b. Paul épousa (PS) Francine (e_2)
'Paul married Francine'
c. Jean-Luc partit (PS) pour l'Afrique. (e_3)
'Jean-Luc left for Africa'
d. et Pedro s'acheta (PS) un âne. (e_4)
'and Pedro bought a donkey'
(Kamp, 1981: 50)

In (10) and (11) the PS sentences can also be called anaphoric because they refer back to (part of) an already known event or set of events.

In my view, the difference between the IMP in (8b) and the PS in (10) and (11) can be characterized as follows. Generally, the type of predication of a sentence presupposes a set of additional properties of the eventuality. For example, the combination of the thematic roles Agent and Patient in the lexical entry of a verb like descendre:

(12) e: $descendre_V\ (x)_{Ag}\ (y)_{Pat}$

predicts that the action is carried out in a certain manner even if it is not overtly expressed:

(13) e: $descendre_V\ (x)_{Ag}\ (y)_{Pat}$ -> Ez: z = Manner (e)

In the same way, non-controlled events (such as die) presuppose the existence of some event which sets off the process:

(14) e: mourir $(x)_{Proc}$ -> Ee': trigger (e', e)

The e' of mourir 'die' can be left unexpressed, appear as de faim 'of hunger', or it can be specified by a subsequent sentence in the IMP. If e' is not expressed by the speaker, the hearer can always ask him/her to specify it (see, for more details, Dik, et al. 1991).

It is my contention that IMP sentences very often provide information about some unexpressed temporal element (manner, motive, consequence, etc.) which is already conceptually present in the meaning of the predicate. This fact explains the irregular character of the fragments discussed by Lascarides et al.: the second sentence gives information about some element which is already present in the discourse domain because it is conceptually associated with the event of the first sentence. In the next sentence I will give a more elaborate analysis of example (1b).

4. Aspectual classes and lexical entries

It is a usual procedure to classify predicates according to a number of parameters which determine the type of eventuality the sentence refers to. I will use here Dik's classification (1989a:91), which is based on the following distinctions:

(15) ± Dynamic
± Transitional (= ± telic/ ± culmination)
± Control

These parameters give rise to the following classification:

(16)

```
                          Eventualities
                                |
               ---------------------------------------
          [-dyn]                                   [+dyn]
             |                                        |
      ---------------                      -----------------------
   -con            +con               +con                     -con
     |               |                  |                        |
  States         Positions        -------------            -------------
                               +trans      -trans       +trans      -trans
                                  |           |            |           |
                        Accomplishment    Activity      Change      Process
```

Fall in (1b) belongs to the class of predicates that can be used to refer to Changes: it is an eventuality that is not controlled by the sentence subject and leads to a transition (or culmination in Moens and Steedman's terms) and a resulting state. I will argue that the lexical entry of fall provides this information, and that it contains also information about the preconditions on falling-events. One of these preconditions is that something has to trigger a non-controlled transition. Since there is no Agent that takes the initiative, there must be something else that sets off the change. The same is true for open in:

(17) The door opened

The interpretor knows not only that the door was not open immediately before the opening event and that the door was open immediately after the event. He/she also knows that there must be some force or agent that caused the opening. If such a force or agent cannot be identified some people start to believe in ghosts. There must be some explanation of why/how the door opened. In the same way:

(18) Pierre trébucha/stumbled

the interpretor can infer that there was some obstacle in the situation in which Pierre stumbled and that he was moving.

Let us now return to fall. This verb has at least three different meanings and within these meanings there are differences between sentences whose subject is animate or non-animate. I will confine myself to animate subjects.

The way I will describe these lexical items is inspired by Partee (1992) and by Rossdeutscher and Kamp (1992). Partee bases herself on Schubert and Pelletier (1988). She suggests that a sentence such as:

(19) Cats always land on their feet

can be analysed in terms of a tripartite structure consisting of an operator (the quantifier) a restrictor and a nuclear scope.

(20)

	S	
Operator	Restrictor	Nuclear Scope
<u>always</u>	(presupposition) cats fall	cats land on their feet

The restrictor specifies a precondition on the eventuality which is mentioned under the Nuclear Scope. (20) reads as follows: it is always the case that, when cat fall, they land on their feet:

(21) ALWAYS (CATS FALL), (CATS LAND ON THEIR FEET)

The precondition is also implicit in (18), but everyone who knows English is capable of inferring that information from this sentence. For (18) the analysis is then as follows:

(22) ALWAYS (x STUMBLE) (x MOVES & y IS AN OBSTACLE)

(22) reads as follows:

(23) 'It is always the case that when x stumbles, x moves and there is an obstacle y'

In what follows I will use the schema of (20) for the description of the meaning of lexical items in combination with a DRS notation. The first part of lexical entries gives syntactic information (the number of arguments and their thematic roles). For <u>fall</u> it is as in (24):

(24) a. $\text{fall}_{V+tr}\ (x_1)_{Proc}$

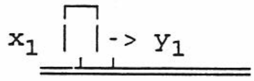
where: +tr: +transitional (+telic; +culmination)

Proc: the entity that undergoes the Change

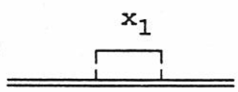
The predicate <u>fall</u> can be used to describe one of the following situations:

(25)

a.



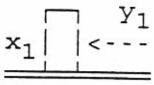
$POS(x_1) = VERT(x_1)$
x_1 is moving
y_1 is obstacle*
lose balance (x_1)



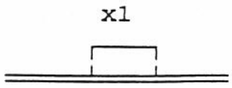
(x_1 lies on the ground)

*for the sake of simplicity I regard as an obstacle also some slippery part of the surface x1 is moving on.

b.

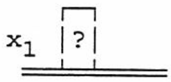


POS(x_1) = VERT (x_1)
loss of balance
by horizontal
force (y_1):

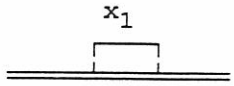


(x_1 lies on the ground)

c.



POS(x1) = VERT
loss of internal
force to maintain
vertical position:



(x_1 lies on the ground)

The semantic part of the lexical entry of <u>fall</u> can now be formulated as follows:

(26) meaning-of <u>fall-1</u>:

a. preconditions on the eventuality:

fall-1

Operator	Restrictor	Nuclear Scope
ALWAYS	eventuality	preconditions-1

K1

x_1 e
e: fall (x_1)
animate (x_1)

K2

e' s' (s'')
s': upright (x_1)
CONTR (x_1, s')
(s'': move (x_1))
e':lose balance (x_1)
e')(e & s')(e

where CONTR means 'has control over';)(: 'immediately anterior to'; s" is not relevant in all the meanings of <u>fall</u>.

b. preconditions on the preconditions of a.:

Operator	Restrictor	Nuclear Scope
ALWAYS	preconditions-1	preconditions-2

K2

(as under a.)

K3

e'' x_2

obstacle (x_2) {s'''}

e'': meet with (x_1, x_2)

OR:

horiz. force (x_2)

e'': meet with (x_2, x_1)

OR:

x_2: x_1's internal force

e'': lose (x_1, x_2)

CAUSE (e'', e')

e'')(e'

c. consequence of falling events:

Operator	Restrictor	Nuclear Scope
ALWAYS	eventuality	consequence

K1

(as under a.)

K4

s_r

on the ground (x_1)

e)(s_r

(26a) accounts for the fact that whenever an individual falls he/she loses his/her balance just before it; (26b) tells us that whenever somebody loses his/her balance there is some event (e") that causes it. (26c) states that whenever somebody falls he/she is on the ground immediately afterwards. Thus, the lexical entry of <u>fall</u> introduces not only the falling event itself, but also the set of eventualities which are associated with it. Note that this configuration of associated eventualities is not an idiosyncratic feature of <u>fall</u>; all the members of the class of Changes have a comparable set of associated eventualities.

If we return now to Lascarides et al.'s example (1b), we can explain why, in the French translation of this example, the IMP has to be used in the second sentence:

(27) a. John fell (= e)/ John tomba (PS) (= e).

b. Max pushed him (= e")./ Max le poussait (IMP) (= e").

The interpretor knows that <u>push</u>/<u>pousser</u> means that a horizontal force is exercised on some individual, and that that force can cause the loss of balance (i.e. e' in (26a)). Consequently the interpretor will understand (27b) as specifying the nature of e", which is already conceptually present in the representation of the falling event.

The lexical entry of (26) can also explain the use of <u>mais</u> 'but' in sentences such as:

(28) Il a glissé, **mais** il n'est pas tombé

'He slipped, **but** didn't fall'

(Jayez, 1988: 25)

Apparently, <u>glisser</u> 'slip' can create the expectation of a loss of balance, followed by a falling-event. This is predicted by (26). In (28) <u>mais</u> cancels this expectation.

Note finally that (26) gives another type of information which is crucial for the interpretation of verb forms which indicate some phase of the event instead of the (whole) event itself. For example:

(29) a. John is going to fall

b. John va tomber

(29a,b) refer to the presupposed situation e'of (26a), in which the individual loses his/her balance. Sentences in the Perfect or in the Passé Composé:

(30) a. John has fallen

b. John est tombé

refer both to the eventuality e and the resulting state s_r of (26c).

Final remarks

The order of events and states in a discourse cannot always be correctly predicted by the tense forms. World knowledge seems necessary to explain the irregular cases. In this paper I propose to account for these 'irregularities' by assuming that lexical entries give information about eventualities which are associated with the event that is overtly expressed in the discourse. In fact, lexical meaning reflects a mixture of linguistic and world knowledge, some of which may be language or culture specific. Using lexical entries for discourse interpretation has the advantage, however, that speakers of the same language share the same intuitions about them and that these intuitions can be tested (for example with the help of continuations with <u>but</u>; cf. (28)).

For French, the lexical entries may explain why the IMP is used even if there is no overt temporal antecedent in the preceding discourse. Since lexical entries predict the existence of unexpressed temporal antecedents which may precede or follow the main event of the predication we can explain why the eventualities introduced by IMP sentences do not always coincide with this main event. In English, there is no formal marker like the IMP, otherwise the interpretation mechanism is the same.

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DISTRIBUTIVITY AND COLLECTIVITY: AN ILL-FOUNDED OPPOSITION*

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0 INTRODUCTION AND ABSTRACT

This paper proposes to get rid of the extremely misleading opposition between collectivity and distributivity, which in my view blocks a deep understanding of how quantification works in natural language. Telling people to stop using a standard distinction they are very much used to, is not an easy job, because it comes close to moralizing. So, it can be expected that the wrong practice will continue even though people accept the correction proposed. Yet I want to give it a try, for two related reasons. The first one is: the abolishment of the distinction brings people home in an area in which they must feel comfortable. I will propose that the term *distributivity* must be bent from its current use —it now means something like 'atomicity', or 'satisfying predication at the atomic level'— to its only proper (and also original) use, namely 'satisfying one of the Boolean laws of distributivity, in particular $A \cap (B \cup C) = (A \cap B) \cup (A \cap C)$'. The second reason is: some scholars seem to be aware that something is conceptually wrong with the collective/distributive distinction, but they do not draw the conclusion as if they still are caught by its magic. This holds good for e.g. Landman (1989) and Van der Does (1992) who sometimes speak about distributivity in genuine Boolean terms, but still maintain a collective/distributive distinction based on an opposition in which atomicity yields a separate reading.

If there is no room at all for an opposing term-pair, and if Boolean distributivity underlies generalized quantification, non-distributivity would cover phenomena which should be outside the realm of quantification (perhaps certain forms of genericity or negation). But this is not what collectivity is about in its current use. The only notion of collectivity that could be potentially interesting from a quantificational point of view is the one which is really structurally prohibitive in that in no model it could be the case that a predicate applies both to a set and to members of a set. But again this is not the notion of collectivity which is used near standardly, where considerations about joint agency or temporality have crept in. This paper will discuss the need for a reorientation on issues involved in the use of terms like *collective, distributive*, and *atomic*.

1 ON THE ORIGIN OF DISTRIBUTIVITY

The opposition between distributivity and collectivity in the current logical-semantic literature on quantification seems to be logical rather than linguistic. To cite an old witness, Jespersen (1913) says the following:

"It is, of course, always possible to emphasize the generic character of an assertion by adding *every* (*every man, every cat*) or *any* (*any man, any cat*), or by using *all* with the plural (*all men, all cats*). This last expression also has the meaning 'all put together'; many logicians distinguish this meaning of the plural as 'collective plural' from the distributive plural', where *all* = 'each'. The difference will be clear from such examples as:

(1) all the angles of a triangle are 180° [= together]
(2) all the angles of a triangle are less then 180° [better: each of ...is]

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(3) all the boys of this form are stronger than their teacher [if working together]
(4) all the boys of this form are able to run faster than their teacher"[1]

If a leading linguist in 1913 refers to an opposition made by "many logicians", we may safely conclude that the two notions were firmly settled in the logical tradition of the time, which is another way of saying that the two concepts date way back to the nineteenth century, or earlier.

On the other hand, going through a number of linguistic works of the last part of the 19th and the beginning of the 20th century, and seeing that the term *distributivity* is lacking one finds some notion of collectivity, mostly in the chapter on plural formation of indo-germanic languages.[2] There are reasons to assume that Jespersen actually took only the term *distributivity* from the logicians and filled the opposite empty place with the traditionally linguistic term *collective*, which had obtained a firm place in grammar, mainly as part of the analysis of the number category. In this respect it is quite striking that Jespersen does not seem to be bothered by the question of whether the two notions are to be tied up with overtly present linguistic forms. Rather than requiring that English have a collective determiner with the meaning '$\text{all}_{\text{collective}}$' which is distinct from a distributive determiner meaning '$\text{all}_{\text{distributive}}$', he simply declares *all* (*the*) to be ambiguous. Thus, he makes the dubious move of distinguishing between all_1 and all_2 in English, on the ground that there is a distributive determiner *every*, whereas it is could also be argued, for example, that the "all put together" in (1) is due to a covert arithmetical +-operation inherent to *be 180°*.[3]

There is a different area where the notion of collectivity belongs, actually its home area. In his major work *Prinzipien der Sprachgeschichte*, Hermann Paul considers Numerus as a grammatical category of a given language "nur durch Ausbildung der Kongruenz", that is, only if this language expresses itself in number agreement. He characterizes Kollektiva (i.e. collective nouns) like *pair*, *herd*, *group*, *committee*, etc. as "zusammenfassende singularische Bezeichnungen für Mehrheiten" (269), i.e. as requiring a singular predicate while expressing plurality.[4] The term *distributivity* itself does not occur in his work, not even in his discussion of the opposition between *jeder* (every) and *alle* (all). Neither did he use the term *collective* in connection with an underlying opposition which nowadays is taken as the collective/distributive opposition.[5]

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[1] I corrected some evident printing errors and added the numbering of Jespersen's examples. He repeats this remark in his *Philosophy of Grammar* 1968 [1924], 203. It is amusing to see that Jespersen calls *collective* what nowadays would rather be called *cumulative*.

[2] E.g. Paul (1920), Brugmann & Delbrück (1911), Meillet (1908). Most attention was given to collective nouns but also to dualis-forms as the expression of a unit whose elements are not counted as individuals. In Royen (1929), we observe that the distributive/collective distinction had been accepted as a genuine linguistic opposition. Distributivity is described as: Man fügt die gezählten Gegenstände nicht zu einer Einheit zusammen, sondern lässt jeden für sich." (1929:613). One does not collect the objects counted in a unit, but one lets everyone for itself. A collection is characterized as "eine kollektive Verbindung ungezählter Gegenstände oder zusammengehöriger Teile" (a collective fusion of uncounted objects or parts belonging together). Bloomfield (1933:221) obviously uses the term collective for collective action by more than one actor. So, there is also a more semantic (or psychological) use of the term, but it does not have distributivity as its counterpart.

[3] Lasersohn (1990) and Scharzschild (1992) discuss the +-operation in terms of a summation-operation in the line of Link (1983). I would suggest that in spite of the attractive idea of homomorphisms perhaps it is better to stress the difference as long as possible because there are linguistically relevant differences between operations in **N** and operations in **R**.

[4] Paul also observes that nearly all Indogermanic languages make a difference between singular and plural (indefinite) pronouns. For him, the opposition between the German *jeder* (every) and *alle* (all) is linguistically important only because *jeder* (every, each) requires a singular form and *alle* (all) a plural form.

[5] In this connection it is revealing that Paul was interested in such developments like the transition from the Gothic *bokos* (literally: letters, Buchstaben) to the singular *Buch* (book). Semantically, a book is a set of letters, but grammatically *a book* takes the singular form.

In spite of the obvious difference between the two linguists with respect to the grammaticalization issue —i.e. the question whether or not a particular semantic distinction ought to be related to its formal expression in a particular natural language—, there is something which they have in common: one could say that for Jespersen it is essential for the collective plural that the predicate *be 180°* and *be stronger than their teacher* not apply to any of the individuals making up the collection: none of the angles in (1) may itself be 180°, whereas in (2) each of the angles satisfies the predicate *be less than 180°*. For convenience, I would like to call this the **kolkhoz**-collectivity: a kolkhoz is owned by a group of individuals but none of these individuals nor any subgroup of them is its owner. In terms of predication in (1): the predicate applies only to the whole group and does not apply to any of its subsets or to atomic individuals.[1]

It is important to realize that the same sort of distinction between levels seems to hold good for collective nouns. If the non-collective noun *child* denotes the set [[child]], any of its individual members x is a child. This is not the case for the collective noun *herd*: none of its individual members is a herd. There is an interpretation of *herd* as the set [[herd]], i.e. {x| x is a herd}, where x must range over herds. But this is not the meaning of the collective noun *herd* in *The herd dispersed.* This *herd* must be defined in terms of atomic individuals which are taken together by a covert plus-operation of some sort on members of the set X, which could be obtained by defining [[herd]] as {X| X is a herd}. In this sense, there is some connection with the collectivity mentioned by Jespersen.

If the above illustrates the normal use of the linguistic term *collective* at the beginning of this century, then we observe that nowadays something has changed drastically in the use of this term as part of the collective/distributive distinction: the kolkhoz-requirement on individuals in the analysis of sentences like (1) has disappeared, as will be shown later on in our discussion of current analyses. On the other hand, if the distributivity in (2) and (4) comes from a logical tradition going back to the 19th century or earlier, then the question becomes: which part of logic did it come from?

There are at least two areas in which distributivity plays an important role: (a) the tradition of Aristotelian syllogism; (b) the more recent mathematical tradition in which the development of Boolean algebra took place resulting in the formulation of the laws of distributivity. To my knowledge, these two areas are not related in a revealing sense.[2] In the Aristotelian tradition *distributive* means 'covering all the members of a given set'. It is one of the opposite terms for those who in Geach's words make "the distinction between cases where a term refers to every one of the objects it denotes and cases where it refers to only some of them" (1972:62). But for the latter case the term *collective* is not appropriate. In concreto, if *all the angles of a triangle* in (2) is distributive, then its opposite in the syllogistic framework is *be less than 180°*. And this predicate is non-distributive because it cannot be said to be true in (2) for all angles in the model that are less than 180°. So, here we see a dead alley called *Geach's scorn*, because the opposition at issue is quite different from what Jespersen could have had in mind and also from what current analyses of the collective/distributive distinction are about.

It turns out to be more promising to take into consideration the Boolean tradition in observing that the basic format for generalized quantification is the Van Benthem (1983) intersection model given in Figure 1.

[1] In this connection, even Jespersen's example in (1) might be analyzed differently. Some mathematicians can live with the idea that a triangle is one straight line with one angle of 180° and the other two of 0°. On the other hand, this does not eliminate the +-operation involved, which might be the essential ingredient of the kolkhoz-collectivity.

[2] A third area could be added by assuming that Jespersen knew about the then new developments in multiple quantification originating in Frege's and Russell's work.

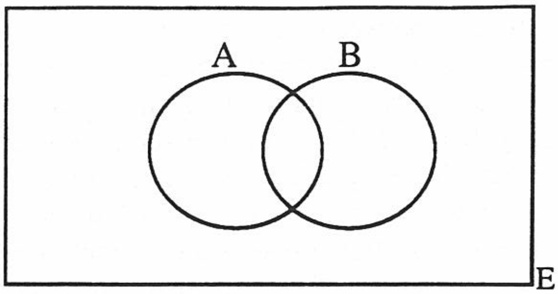

Figure 1

Sentences of the form $[_S[_{NP}[\text{Det N}]\ \text{VP}]$ are analyzed in terms of a relation between the determiner Det, the Noun N and the predicate VP. Semantically, this corresponds to a relation $D_E(A,B)$, where E is the domain of interpretation, $D_E = [\![\text{Det}]\!]$, $A = [\![\text{N}]\!]$ and $B = [\![\text{VP}]\!]$, and where the relation expressed by a determiner is standardly defined in terms of the intersection $A \cap B$, among other sets. For example, the determiner *all the* may be defined as giving the information that the intersection between A and B yields A itself:

(5) $[\![\text{all the}_E]\!](A)(B) = 1 \text{ iff } B \in \{X \subseteq E \mid A \cap X = A\}$

Applied to (4), this means that (4) is true if and only if the set of entities with the property of running faster than their teachers intersects with the set of boys A in a specific way (for *all the* the set A is included in B; for *some* $A \cap B$ would contain at least two elements, for *three* it would contain three elements, etc.).

If the $\cap$-operation determines the predication-relation between $[\![\text{N}]\!]$ and $[\![\text{VP}]\!]$, and if furthermore the $\cup$-operation is around, as in (6) which entails (7):

(6) Neither man walked or laughed
(7) Neither man walked and neither man laughed

then an important principle discovered in the last century, and laid down in one of the distributive laws of Boolean algebra (8) is structurally connected with generalized quantification, as demonstrated in (9).

(8) $X \cap (Y \cup Z) = (X \cap Y) \cup (X \cap Z)$
(9) $[\![\text{N}]\!] \cap ([\![\text{VP}_1]\!] \cup [\![\text{VP}_2]\!]) = ([\![\text{N} \cap [\![\text{VP}_1]\!]) \cup ([\![\text{N}]\!] \cap [\![\text{VP}_2]\!])$

This type of distributivity (and its limitations) is studied extensively in the literature of generalized quantification theory (e.g. Zwarts 1986, Keenan & Faltz 1986), but it will play a minor role in the present discussion of distributive and collective quantification. We will be more interested in a version of (9) in which VP_1 and VP_2 are not different predicates but rather subsets of the predicate VP in the sentence under analysis. This could hold for instance in sentences like:

(10) John and Mary walked
(11) Two students walked

Suppose that John and Mary are students $\{\text{John, Mary}\} \subseteq [\![\text{student}]\!]$ and that (10) and (11) is true for the same situation. Then the set $[\![\text{student}]\!] \cap [\![\text{walk}]\!] = \{\text{John, Mary}\} = \{\text{John}\} \cup \{\text{Mary}\}$, where the $\cup$-operation is overtly reflected in (10) and tacitly assumed in (11). The present paper will be focussed on this tacit use of the $\cup$-operation in the predication based on intersection, a use which comes out more overtly if NPs are being treated as denoting semantic objects of type $\langle\langle\langle e,t\rangle,t\rangle,t\rangle$, and VP-denotations as collections of sets. This will provide the structure of the intersection necessary for the $\cup$-operation.

The analysis of distributivity in terms of the law applied in (6) will lead to a radical redefinition of the notion of distributivity as near standardly used in current analyses of plurality and to the detachment from its illegal partner, the notion of collectivity. Before elaborating this point, I will first review some current interpretations of the two notions collecting the ingredients motivating the conceptual shift to come.

2. NP OR VP?

Which constituents harbour the information responsible for the difference between a collective and a distributive interpretation of sentences? Both Hausser (1974) and Bennett (1975) distinguished between distributive and collective NPs, but also between distributive and collective predicates. Scha (1981) declared the predicate "neutral" with respect to the collective/distributive opposition, thus restricting it to the NP only. One of the reasons for Scha to reject doubling was to avoid complications in his syntax, because on e.g. Bennett's approach a special syntactic category must be assigned to collective nouns like *crowd*, *committee*, and to predicates like *numerous*, but also the verb *walk* occurring with collective nouns must be distinguished from the verb *walk* used distributively. For sentences like *All men applauded Mary* Bennett's system had to distinguish between a distributive term phrase T and a collective term phrase T, as well as between a distributive verb phrase IV and a collective verb phrase IV. Such a duplication over both a function (subject NP) and its argument (the predicate) requires matching rules. The only provision for verbs made by Scha is a meaning postulate for verbs like *walk* requiring for a sentence like *The boys walk* that if the boys walk, each individual boy walks. In this way, distributivity in Scha's sense is lexically specified for verbs like *walk*, whereas *gather* is excluded from applying to individuals. It should be observed that from a linguistic point of view this solution is rather counterintuitive: the *walk*-property is assigned at the collective level and then distributed down to the atoms, whereas intuitively *walk* is to be considered a property to be assigned to atoms (cf. Van der Does 1992 for a correction on Scha)..

At the other side of the cost/profit account, Scha complicates the binary distinction for NPs, replacing it by a ternary distinction: Distributive, Collective 1 and Collective 2. So, NPs with numerals, such as *three men*, *two tables*, etc. are systematically ambiguous between a D-, a C1-, and a C2-reading, as shown in (12).

(12)
D: $\lambda P_{\langle\langle e,t\rangle,t\rangle} |\{X_{\langle e,t\rangle} \in N^* : P(X)\}| = n$
C1: $\lambda P_{\langle\langle e,t\rangle,t\rangle} \exists X_{\langle e,t\rangle} \in \{Y_{\langle e,t\rangle} \subseteq \bigcup N^* : |Y| = n\} : P(X)$
C2: $\lambda P_{\langle\langle e,t\rangle,t\rangle} |\bigcup\{X_{\langle e,t\rangle} \subseteq \bigcup N^* : P(X)\}| = n$

N* is the set of all (atomic) singletons construed from the N-denotation. An NP denotes a characteristic function taking collections *P* and mapping them onto 1 if and only if *P* contains the set X as defined in the definitions. On a D-reading an NP picks out all the atoms. So, like Hausser and Bennett, Scha takes distributivity as the reading corresponding to a situation in which the predicate is applied to each individual atom. However, he complicates the notion of collectivity. His C1-reading models groups by means of sets: it makes sure for *three men* that there is a set X of men having 3 members to which the predicate *P* applies as a whole. The C2-reading is a sort of bridge between C1 and D: for *three men P* maps those subsets of men to 1 whose union satisfies the cardinality condition 3.

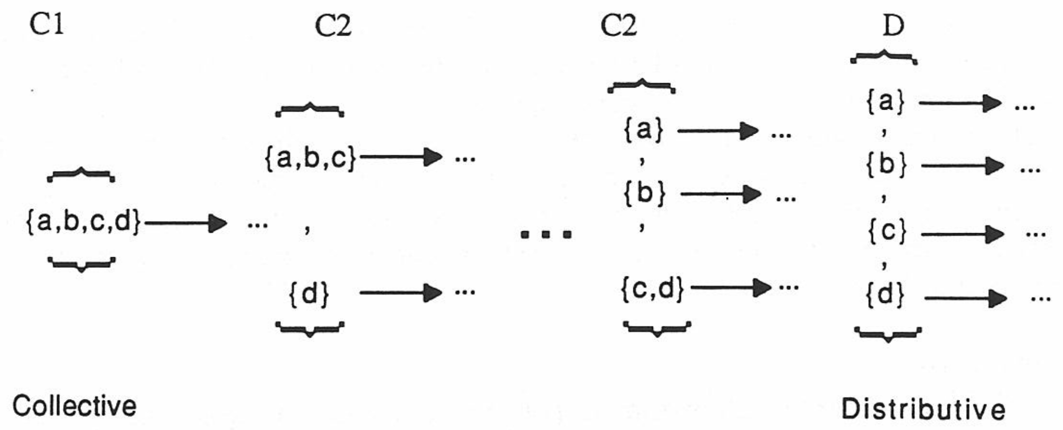

Figure 2

Thus, Scha's formal system accounts for all the possibilities from left to right in Figure 2. At the most left-hand side, predication (symbolized by an arrow) takes the group as a whole, at the most right-hand side it takes the singletons. Scha mixes two sorts of consideration: he wants to maintain a traditional binary opposition (the poles in Figure 2) and for that he uses the labels C1 and D, whereas his wish to account for the intermediate forms of predication makes him distinguish C2. This is fatal for his system, however, because the extremes in Figure 2 can be yielded by C2 itself, which implies that the number of readings is unnecessarily high.

C1 and C2 cannot be connected with the kolkhoz-notion in Jespersen (1913): for Scha not only a group but also its subsets among which the singletons may satisfy a certain predicate. For example, under both the C1- and the C2-reading of a sentence like *Four men walked*, each individual man may have walked. Actually, it is quite hard to think of a kolkhoz-interpretation, but it is not excluded with a little help of morbid imagination, if Siamese twins do not suffice to make the point. Conceptually something very interesting has taken place: a drastic change of meaning in the notion of collectivity if Jespersen (and perhaps Paul) are taken as a reference point.

Link (1983;1984;1987) can also be placed in the tradition in which the collective/distributive opposition is taken for granted, but there are two important differences with Scha. Firstly, Link confronts Scha's set-theoretical approach with his own lattice-theoretical approach (cf. Landman 1989 for a thorough analysis, but also Lønning 1989 and Van der Does 1992). Secondly, he holds that the collective/distributive distinction is a matter of the predicate rather than of the NP. For him predicates like *disperse*, *gather*, etc. are collective, whereas predicates like *sleep* and *walk* are (at least) distributive. In Link (1984:18), for example, sentences like (13):

(13) All soldiers slept

raise the question: "Can a distributive predicate like *sleep* also be true for the whole group?". Assume that there are three soldiers a, b and c, then the question becomes: "Should the group of the three soldiers be made element, over and above the single elements a, b and c?" No, Link says, extending this problem to intermediate group levels, because in sentences like *All soldiers received 100 DM*, no paymaster would ever think of paying 700 DM which would be necessary if the predicate *receive* would operate on the eight members of $\wp(\{a,b,c\})$ minus the empty set. This made Link distinguish between the predicates ^{D}sleep' and sleep', the former being distributive, the latter collective. The verb *sleep* is therefore called a *mixed predicate* (cf. also Landman 1989:567).

As said, Link takes the distributive/collective distinction for granted, so one has to look for casual circumscriptions in his papers to see what he has in mind. In Link (1984:18f.), for example, the intuitive meaning connected with *collective* is described for sentences like:

(14) Three men lifted the piano

On the collective reading, the sentence is said to refer "to one single act of lifting the piano", whereas on the distributive reading (14) says that there are "three separate acts of lifting involved". Link (1987:153) speaks about mixed predicates with respect to the collective/distributive distinction. Thus, *lift a rock* is a mixed predicate like *sleep* because it can be true of atoms and i-sums.[1] With respect to (14) this would mean that if a, b and c are the men having lifted the piano, *lifted the piano* may be true of {a,b,c}, {a,b}, {a,c}, {b,c} as well as of the singletons. However, Link restricts this range by saying: "there might be either three liftings involved or a single one dependent on the distributive or collective interpretation chosen" (*ibidem*). Thus, in his writings Link defines the collective interpretation in terms of a single event in which a group acts as a total, whereas the distributive interpretation clearly concerns individual acts at the atomic level (1983:309; 1984:18; 1987:171).[2]

Link's interpretation of collectivity is clearly not a kolkhoz-one: Link does not exclude the possibility of a collective predicate applying also to the individuals involved, because on the collective reading of (13) it is clear that individual soldiers must have slept. The interpretation of collectivity in terms of applicability of the predicate at a certain type-logical level is mixed up or replaced by considerations concerning agency, temporality and other semantic factors.

As far as the number of readings is concerned, Link wins from Scha by one reading. Because Scha's NPs are (at least) triply ambiguous, sentences containing two NPs are (at least) 9 times ambiguous. Because Link combines two assumptions he produces eight different readings for a sentences of the form NP_1 [V NP_2]. These assumptions are: (a) NP_1 and NP_2 have wide and narrow scope with respect to one another; (b) the predicate V is four times ambiguous, as shown in (15):

(15)	V	doubly collective	${}^{D\bullet}V$	left distributive
	${}^{\bullet D}V$	right distributive	${}^{DD}V$	doubly distributive

Due to scope reversal, these interpretations of the predicate appear in the sequence $NP_1 \ldots NP_2$ as well as in the order $NP_2 \ldots NP_1$, which brings the number of readings to eight.

In my opinion, (15) reveals that in spite of his saying so Link no longer attributes the collective/distributive distinction to the predicate only, but rather (or also) to its arguments. For suppose that a verb like *lift* is analyzed as in (14), what should a child learn about it? Should it learn that there are eight verbs *lift* (reducing to six because some of them produce the same logical forms)? Of course not, but the only alternative seems to be that it learns about *lift* that it takes precisely eight sorts of combinatorial possibilities, even though the combinatorial possibilities based on the cardinalities of the NPs are many more. The fact that this involves some matching between the V and its NPs, makes it hard to escape from the conclusion that Link invokes principles concerning the interaction between NP and VP. This boils down to returning to the position adopted by Hausser and Bennett.

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[1] An i-sum is the lattice-theoretical counterpart of a set construed from singletons.

[2] Link (1983: 309) explains his definition of a distributive predicate (i) $Distr(P) \equiv \forall x(P(x) \rightarrow Atom(x)$ by saying that these predicates "seem to admit only atoms to their extension". I disagree with Van der Does (1992:64) who ascribes to Link the suggestion that "distributive predicates should be seen as obtained from atomic predicates by means of 'pluralization'". This would mean that Link would take distributivity as the property of being closed under subset and closed under union. In his formalism, Link clearly connects the notion of distributivity exclusively with predicates restricted to atoms.

The literature discussed is guided by the following assumptions:

A. there is a natural opposition between distributive (atoms) and collective (group);
B. it should be attributed to VP or to NP in forms like NP [$_{VP}$ V] and NP [$_{VP}$ V NP];
•Alternative 1: put it in the NP and also in the VP (Hausser, Bennett);
•Alternative 2: put it only in the NP (Scha);
•Alternative 3: put it in the VP (Link, if we believe what he says).

In more recent literature in which certain modifications are proposed with respect to Scha and/or Link, such as Landman (1987;1989), Roberts (1987a,b), Lasersohn (1990), Lønning (1989;1991), Verkuyl & Van der Does (1991), Van der Does (1992) we see that the collective/distributive distinction along the line 'group vs. atoms', is taken for granted as well. A lot of energy is given to sorting out which of the three alternatives is correct. The fourth alternative is: allow yourself the thought that there might be something wrong with assumption A. This doubt was expressed at the close of Verkuyl (1992).

3. THE SCALE APPROACH

As pointed out in Verkuyl & Van der Does (1991), Scha's C2-reading covers the whole range between the two poles in Figure 2. For example, the C2-reading covers all situations made true by a sentence like (16):

(16) Three men lifted two tables

They proposed to have just one reading for sentences like (16) by including in the NP representation information about the possible ways in which the members of the NP denotation may be involved in the predication. However, they interpreted Figure 2 as a scale going from purely Collective to purely Distributive. To achieve this technically they extended the representation of NPs like *three* N, so as to contain the information that the set of three men in (16) and the set of three children in (17) is subjected to some form of covering, where a cover of a set X is defined as a collection P of non-empty subsets of X such that $\bigcup P = X$.

(17) Three children came in

In this way, the intersection A∩B in Figure 1 is given a cover-structure plus some additional constraint for sentences like (17) showing up as the collection P of sets in (18).

(18) $\exists Z[Z \subseteq [\![child]\!] \wedge |Z|=3 \wedge \exists P \, ps Z[P=\{V \cap [\![child]\!] \mid [\![came\_in]\!](V)\}]]$

Representation (18) can be read as follows: it says that there is a set Z of three children and that there is a collection P partitioning Z such that P is the collection of sets V∩⟦child⟧ of walking individuals. In (18), the following types are involved:[1]

(19)

Phrases		Variables	
NP	$<<<e,t>,t>,t>$	P, Q, R	$<<e,t>,t>$
Det	$<<e,t>,<<<e,t>,t>,t>>$	U,V,W,X,Y,Z	$<e,t>$
N	$<e,t>$	$V_{1\text{-place}}$	$<<e,t>,t>$
VP	$<<e,t>,t>$	$V_{2\text{-place}}$	$<<e,t>,<<e,t>,t>>$

[1] The lift involved in defining a determiner as a relation between a set and a collection of sets will be discussed below in more detail. Here is suffices to point out that it is recognizable in the part in which sets U and V intersect with N-denotations.

The ps in (18) stands for partition or pseudo-partition. A partition is a cover with the constraint that for any two subsets $X_i, X_j \subseteq X$ either $X_i = X_j$ or $X_i \cap X_j = \varnothing$. Inherent to a partition is a cardinality requirement, because the number of its cells never exceeds the cardinality of the set it partitions. A pseudo-partition is a weakened version of a partition in that it is a cover plus the constraint that if P covers X, $|P| \leq |X|$. A pseudo-partition is meant to allow a child in (17) to come in more than once, but to maintain the cardinality requirement of the partition. I come back to a discussion of different ways of constraining covers and possible linguistic arguments for either of them shortly. Sentence (16) is represented by (20).

(20) $\exists Z[Z \subseteq [\![man]\!] \wedge |Z|=3 \wedge \exists P \text{ps} Z[P=\{V \cap [\![man]\!] | \exists W[W \subseteq [\![table]\!] \wedge |W|=2 \wedge \exists Q \text{ps} W[Q=\{U \cap [\![table]\!] | [\![lift]\!](U)(V)\}]]\}]]$

It says that there is a set Z of three men and that there is a collection P partitioning Z such that P is the collection of sets $V \cap [\![man]\!]$ such that for each element of P there is a set W of two tables which is partitioned by a collection Q such that the elements U of Q are lifted by V. Note again that in their treatment of the notion of collectivity nothing prevents singletons of an NP denotation to satisfy the predicate. So, like Scha and Link, Verkuyl & Van der Does (1991) distinguish no kolkhoz-collectivity.

Crucial for the analysis is the presence of the two existential quantifiers introducing the collections P and Q. This is mere construal on the basis of our knowledge that any set can be partitioned if an appropriate equivalence relation is around. In Verkuyl (1987;1988) this equivalence relation is identified as thematic equivalence, i.e. as the way the members of an argument denotation are "drawn into" the predication on the basis of being associated with the same index. For the possible configurations of P one might (very roughly) represent this (for different i,j and k) in the form of sets of pairs:

(21) $\{\langle i,\{a,b,c\}\rangle\}$
$\{\langle i,\{a,b\}\rangle,\langle j,\{c\}\rangle\}$, $\{\langle i,\{a\}\rangle,\langle j,\{b,c\}\rangle\}$, $\{\langle i,\{a,c\}\rangle,\langle j,\{b\}\rangle\}$
$\{\langle i,\{a\}\rangle,\langle j,\{b\}\rangle, \langle k,\{c\}\rangle\}$.

where the pairs are elements of a function making the cells of the partition dependent on an indices. Indices may be seen as a way to actualize (e.g. in real time) one of the options kept open by the partitioning P. The existential quantifier $\exists P$ in (18) is intended to express fundamental indeterminacy with respect to which structuring actually took place in a particular situation: it only warrants that there is one actualized option in (21).[1] Note in passing that Link's paymaster in (22)

(22) Three soldiers received 100 DM

does not have to pay 700 DM now: the sum total cannot exceed 300DM, but essential for this sentence is that it does not give away sufficient information about what happened. Note also that the soldiers may have received their 100DM in parts, i.e. at different indices they received a proper subset of 100 DM until they got at the individual sum total, due to genuine partitioning.

Essential for the Verkuyl & Van der Does-analysis was that the idea of a scale —i.e. one

[1] In Verkuyl (to appear), the structuring of P is taken as an indexed family of sets which means that P is a function with the index set as its domain and a family of sets as its range. This way of analyzing sentences like (16) explains why these sentences are terminative. For the present (atemporal) analysis the indices do not play a role, but in the last section their use will be explained in more detail.

reading varying from purely collective to purely distributive in Figure 2— can be connected with the working of the existential quantifier over collections like P and Q in (18) and (20). The quantifier covers the full range, warranting that given a certain model and an interpretation of the sentence in question one of the configurations on the scale will be actualized. Hence there is no need to distinguish separate readings. Rather, the analysis recognizes that there is structural underinformation by using just the verb and its arguments and leaving out such modifiers like *one-by-one*, *together*, *in groups*, etc.

Lønning (pers. comm; 1991) pointed out that there is a problem connected with the use of representations like (20) which are inherently asymmetric. This can be seen by leaving out some of its parts:

(23) $\exists Z[Z \subseteq [\![N]\!] \wedge \ldots \wedge \exists P \mathrm{ps} Z[P = \{V \cap [\![N]\!] \mid \exists W[W \subseteq [\![N]\!] \ \ldots\ ]$

This says that for each of the cells of P there is a W such that .... This means that for sentences like:

(24) Three boys bought a boat

the following may happen: boy_1 and boy_2 bought boat_1, whereas boy_3 bought boat_2. Many speakers appear to reject this interpretation: they can interpret (24) as pertaining to three boats or to one boat, but not to two boats. For the three soldiers in (20) it might mean that they received 200 DM all together.

Judgments are difficult. I tend to reject the two-boat-interpretation hesitantly. Hesitantly, in view of counting situations and situations in which joint labour is counted as full labour. Take *three linguists of our department wrote a book this year* said by a bureaucrat counting the output of the faculty. In my faculty, on each linguist's list it would be mentioned that he wrote a book, whereas the department is booked for having as its output two books, because Michael and Jan wrote a book together and Eric wrote one on his own. Also, Lønning's *Four boys shared three pizza's* can be interpreted as saying that Harry, John and Bill shared three pizza's and Bill and Mary one pizza. As pointed out in Verkuyl (1992), at the counter of a restaurant this sentence sounds quite different (and more acceptable) from other situations, because on the bill the seller can distinguish between two Bills. Index-dependency seems to be involved here in the quantification of individuals. A person can call at two different times and so be counted for two different persons by the phone company. In spite of these interpretive possibilities, I will have to face Lønning's objection, because it is obvious that there is something highly marked under the two boats-interpretation.

Given the fact that asymmetry is essential to my view on quantification involving temporal structure —the internal argument is associated with the verb more closely than the external argument, I cannot meet Lønning's objections by simply undoing the asymmetry. One way of meeting them though is to assume that there are restrictions on the partitioning of the external argument NP which would solve the problem. These restrictions were proposed independently of the present discussion about (24) in Verkuyl (1988). They will be treated in more detail in the last section.

4. THREE READINGS, ONE FORMAT

Partly influenced by Lønning's criticism on the One Reading hypothesis discussed above, Van der Does (1992) fell back on three readings for NPs, (a) the distributive reading, (b) the collective reading, and (c) the cumulative reading. Also important in this change of position is his conviction that even though the asymmetric approach inherent to (23) is basically correct for the cases discussed in Verkuyl & Van der Does (1991), it fails to account for the cumulative reading which on his view requires independency of the two arguments involved. Furthermore, Van der Does sees problems with respect to the constraints on the covering. For example, he rejects a pseudo-partition for (17) on the ground that the number of reappearances of one and the same child should not be constrained by the cardinality of the set of children having come in. In other words, (17) may be true even if it turned out that one of the children had come in seven times. A third reason for Van der Does is that in Scha's theory it remains unclear how the D-reading of NPs with numerals can be formulated in terms of the standard denotation of determiners as a relation between sets.

For myself the pseudo-partition constraint on *P* and *Q* was quite unsatisfactorily forced upon us by not finding a good solution for the problem raised by the returning child. It meant a relaxation as compared with the more constrained position taken in earlier work (e.g. Verkuyl 1987;1988) in which genuine partitioning is the required option. I have now readopted my earlier position with the help of a new principle derived from my work on aspectuality: Once Counted, Always Counted. The ideology behind this OCAC-principle comes from a theory of aspectuality in which a crucial place is given to the presence of cardinality information of the NP, either directly (numerals) or indirectly (*all*, *the*, *some*, *many*, etc.).[1] If one assumes that determiners are used to express cardinality information, as becomes visible for example in (18) and (20), then a principle of relevance requires that this information bears on the way the predicate is being applied. In (17) *Three children came in* it is the number of possible combinatorial configurations allowed by the number 3 that should be seen as crucial. The number of times each of the three children came in, is irrelevant given the information expressed by (17). Otherwise one could have added modifiers like *n times*, which focus on the number of times an action took place. The working of the OCAC-principle can nicely illustrated by sentences like:

(25) Three prisoners were hanging along the road.

Here either the prisoners were hanging together or the speaker, say Peter, reports about a two:one configuration or about three individuals hanging separately on different locations (in a 1:1:1- or 1:2-configuration). His (25) can be taken as a report about what Peter saw while moving along the road. Suppose that Peter took the road several times, so that he saw prisoner 1 and prisoner 2 five times: he would simply use (25) adopting the OCAC-principle in his use of this sentence, as he would have done in the sentence *Three prisoners were executed this afternoon*. In general, if a predication is about an external argument NP, the cardinality of the NP-denotation is relevant for the property of being closed under subset, given a (thematic) equivalence relation (see for more details, Verkuyl to appear).

Van der Does (1992:36ff) discusses six potential determiner readings which he reduces to three. I will pay some attention to what may be considered a setback with respect to the number of readings in Verkuyl & Van der Does (1991), firstly because it still improves on Scha and Link, and also because it gives me the opportunity to show how the law of distributivity is hidden in the representations discussed so far. This will make it possible to make the main point of the present paper. Van der Does assigns three readings to (16) *Three men lifted two tables*.

Distributive reading:

(26) $\exists Z[Z \subseteq [\![\text{man}]\!] \wedge |Z|=3 \wedge \exists P \mathrm{cv} Z[P=\mathrm{AT}([\![\text{man}]\!]) \cap \{V| \exists W[W \subseteq [\![\text{table}]\!]$
$\wedge |W|=2 \wedge \exists Q \mathrm{cv} W[Q=\{U \cap [\![\text{table}]\!] | \; [\![\text{lift}]\!](U)(V)\}]]\}]]$

[1] With the latter I simply mean that in all these cases we know that there is a cardinality number, only we mostly do not know which one it is.

Collective reading

(27) $\exists Z[Z \subseteq \llbracket man \rrbracket \wedge |Z|=3 \wedge \exists P \mathrm{cv} Z[P = \{V | \exists W[W \subseteq \llbracket table \rrbracket \wedge |W|=2$
$\wedge\ \exists Q \mathrm{cv} W[Q = \{U \cap \llbracket table \rrbracket |\ \llbracket lift \rrbracket(U)(V)\}]]\}]]$

Cumulative reading

(28) $\llbracket 3 \rrbracket(\llbracket man \rrbracket)(\bigcup \mathrm{DOM}(\llbracket lift \rrbracket \cap \wp(\llbracket man \rrbracket) \times \wp(\llbracket table \rrbracket)))$
$\wedge\ \llbracket 2 \rrbracket(\llbracket table \rrbracket)(\bigcup \mathrm{RG}(\llbracket lift \rrbracket \cap \wp(\llbracket man \rrbracket) \times \wp(\llbracket table \rrbracket)))$

In (26) the external argument *three men* is partitioned into a set of singletons for each of which there is a set of tables covered by Q such that the cells of Q were lifted by it. Note that there is no restriction on the cover for the internal argument *two tables*. Van der Does calls this the neutral reading for the NP. It allows him to interpret (16) as saying that each of the three men might have re-lifted each of the two tables an indefinite number of times. The same applies to *two tables* in (27), where the external argument *three men* is now taken as expressing that there is a group of three men which is covered by P. Because the predication applies to P as a whole, the cover does not express its internal structure. Van der Does gives the collective reading an adjectival interpretation: there might be a group of men with a higher cardinality lifting two tables as well. Finally, (28) says that the total number of men involved in the lift-relation between men and tables is three and that the total number of tables involved in this relation is 2.

It is important to see that these three readings result here from the combination of three different sorts of determiners, which Van der Does calls D_1 (distributive), C_2^a (adjectivally collective) and N_3 (neutral). It is the combination of two NPs with neutrally interpreted determiners that gives the cumulative reading in (28). The definitions of the determiners Det are the following:

(29) D_1 $\lambda D \lambda X \lambda P. \exists Z \subseteq X[D(X)(Z) \wedge \exists Q \mathrm{cv} Z[Q = \mathrm{AT}(X) \cap P]$
(30) C_2^a $\lambda D \lambda X \lambda P. \exists Z \subseteq X[D(X)(Z) \wedge P(Z)]$
(31) N_3 $\lambda D \lambda X \lambda P. \exists Z \subseteq X[D(X)(Z) \wedge \exists Q \mathrm{cv} Z[Q = \{Z \cap X | P\ (Z)\}]$

Recall that X is of type <*e*,*t*> and *P* of type <<*e*,*t*>,*t*>.[1] The subscripts on D, C and N "point to the way in which the noun and the verb phrase extension are related to each other. 1: only the atoms formed out of the noun extension matter; 2: only the collections formed out of the noun extension matter; 3: all members in the noun extension matter that occur in a collection in the verb phrase extension" (1992:37).

Van der Does rejects an N_2-reading (32) for (16) as in (33):

(32) N_2 $\lambda D \lambda X \lambda Y. \exists Z \subseteq X[D(X)(Z) \wedge \wp(Z) \subseteq P\ ]$
(33) $\exists Z[Z \subseteq \llbracket man \rrbracket \wedge |Z|=3 \wedge \exists P \mathrm{cv} Z[P = \wp(\llbracket man \rrbracket) \cap \{V | \exists W[W \subseteq \llbracket table \rrbracket \wedge |W|=2 \wedge$
$\exists Q \mathrm{cv} W[Q = \{U \cap \llbracket table \rrbracket |\ \llbracket lift \rrbracket(U)(V)\}]]\}]]$

which would express Scha's C2-reading. This is because it would make it possible for the men to have lifted two × the cardinality of the richest cover $\wp(Z)$, i.e. 12 tables. It is important to point out that this proliferation is due to the fact that Van der Does does not apply the "Once Counted, Always Counted"-principle (with a liberal approach of what happened internally) inherent to the genuine partition relation ps. If he would apply it, he would be able to stick to D_1, N_2 and N_3 :

(34) D_1 $\lambda D \lambda X \lambda P. D(X)(\bigcup(P\,|^{1}_{X}))$

---

[1] A determiner is of type <<*e*,*t*>,<<<*e*,*t*>,*t*>,*t*>>. D is standardly of type <<*e*,*t*>,<<*e*,*t*>,*t*>>, so in the definition of a determiner there is a lift involved. This lift remained implicit in Scha (1981), but it was spelled out in Van der Does (1992:36ff) which led to some technical corrections of Scha's formalism.

(35) N_2 $\lambda D\lambda X\lambda P.D(X)(\bigcup(P\,|^2_X))$
(36) N_3 $\lambda D\lambda X\lambda P.D(X)(\bigcup(P\,|^3_X))$

where $|^i$ ($1 \leq i \leq 3$) is a function restricting P to X, and defined as follows (1992:37):

(37) $|^1$ $\lambda X\lambda P.\mathrm{AT}(X) \cap P$
(38) $|^2$ $\lambda X\lambda P.\wp(X) \cap P$
(39) $|^3$ $\lambda X\lambda P.\lambda Y\exists Z[P\,(Z) \wedge Y = Z \cap X]$

The generalization $|^i$ over the three functions implies, of course, that the general format of (34) – (36) is (40):

(40) $\lambda D\lambda X\lambda P.D(X)(\bigcup P\,|^i_X)$

Van der Does C^a_2-reading in (30) can also be modelled after this format by adding the adjectival requirement:

(41) $|^{2a}$ $\lambda X\lambda P.\lambda Y\exists Z[P\,(Z) \wedge Y = Z]$

This means that Van der Does three readings all fit in the scheme (40). The obvious differences between his position and the one I am going to take is that on his view i varies over three different readings determined by (37), (40) and (39), whereas I try to maintain the idea of reducing the three varieties covered by i to something which comes close to (39).

There is an alternative for (37), (41) and (39) discussed in Van der Does, which is only possible for those who accept a partitioning as the basis for the structuring of the collection of sets denoted by the predicate. In that case (40) would yield:

(42) $\lambda D\lambda X\lambda P.\exists Z \subseteq X[\,D(X)(Z) \wedge \exists Q\mathrm{ps}Z[Q = P\,|^i_X]]$

Van der Does observes that for each i the lifts involved turn out to be equivalent to each other. This means that both Van der Does' position in which he distinguishes between (26), (27) and (28) and my own position which reduces the readings to just one representation (42), are both based on (40).

5 DISTRIBUTIVITY AS A BOOLEAN NOTION

Recall that D in (40) assigns the $\cap$-relation between X and $\bigcup P\,|^i_X$, i.e. between X and the union of all sets V intersected with X which form the collection P. In other words, (40) gives us the format that we were looking for in section 1, as can be seen from (43):

(43) $X \cap \bigcup P\,|^i_X = \bigcup\{X \cap Y \mid P(Y)\}$

This means that if the intersection relation given in Figure 1 is interpreted as holding on the basis of an NP of type <<<*e*,*t*>,*t*>,*t*> taking a VP of type <<*e*,*t*>,*t*> as its argument, an analysis of the determiner in terms of the structure (40) is directly related to the law of distributivity (8): the predication relation meets its format and hence any determiner analyzed in terms of (40) can be analyzed further into predications holding between smaller parts, with singletons at the "lowest level".

Distributivity in the new sense of 'meeting the law of distributivity' (43) is essentially a property of the relation expressed by the determiner as a whole. When necessary I will call this form *Boolean distributivity* to distinguish it from the current wrongly used term pertaining to atoms only. Meeting the law of distributivity means that if we assume the basic format of generalized quantification $D_E(A,B)$, where D_E is taken as a relation between A and B, then Boolean distributivity is granted as soon as this relation expresses the proper sortal conditions for quantification. In this sense, Boolean distributivity of D_E is the condition that its two arguments fit type-logically. Mostly, it is B which puts constraints on A, as in *disperse*, *numerous*, etc., sometimes it is A which constrains B, as in *pairs*, *herds*, *trios*, etc., and sometimes constraints on D_E will be due to the interaction between A and B, as in *All participants of the festival played Schubert's Octet*. It is important to observe that one still could say that a predicate is Boolean-distributive: we then just say that the predicate meets the conditions on the D_E-relation in question, given the set A.

This reconceptualization of the notion of distributivity is compatible with the view of a determiner being so generally defined that it allows the whole scale between the smallest elements (atoms) and the "lump sum". So, in fact the scale idea expressed in Figure 2 can be maintained but without the labels Distributivity and Collectivity at the poles. The notion of Boolean distributivity now covers the whole scale:

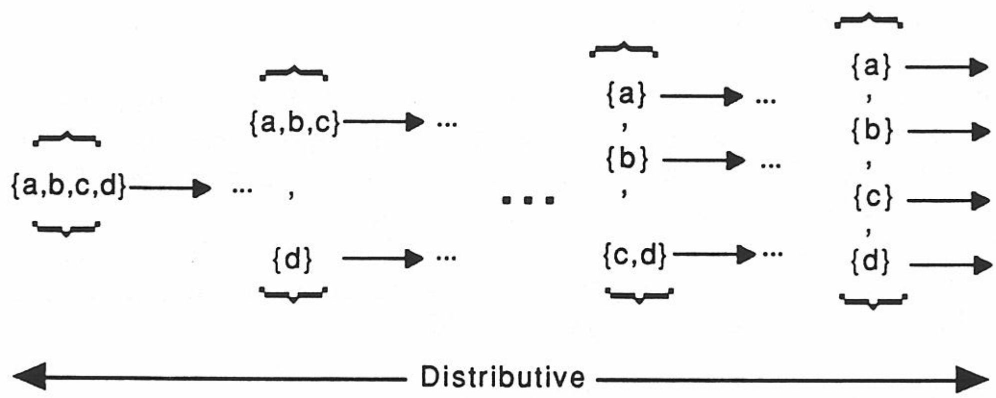

Figure 3

This picture has far-reaching consequences for our understanding of what the notion of distributivity is about. It no longer should apply to the situation in which an NP-denotation is taken as a set of atoms or as the right hand side of (43) with the sets $V_1, \ldots, V_n$ all taken as singletons, but rather to a situation in which a $D_E(A,B)$ satisfies the Boolean law of distributivity in its form (43) due to the fact that D_E is defined in terms of (40).

Distributivity as captured by the equation (43) is formulated as a set-theoretical equation. If a "lump sum" is given by an NP by compressing the numerical information —in sentences like (17), (16), and (24) we say *three children*, *the children*, *all children*, etc. rather than *John and Mary and Peter*—, then the determiner structure of the form (40) gives us the right to deduce from (17) that we may get to the atoms as in (44) and to all intermediate forms, because (45) and (46) can be further analyzed into the atoms by applying (43).

(44) John came in and Mary came in and Peter came in
(45) John and Mary came in and Peter came in
(46) John came in and Mary and Peter came in

We meet here the property of being closed under subset, which is one property of (43). It is important to note that the grouping of John and Mary in (45) does not force us to assume that first John and Mary came in together and that Peter came in at a later stage, because the use of conjunction is not necessarily tied up with expressing temporal information. For example, the grouping of John and Mary in (45) may be due to the fact that the speaker of (45) went through a list reading names, so that the grouping is part of the organizing of data in front of him. Likewise, the differentiation into atoms in (44) does not give any conclusive information about the temporal structure to which (44) applies.

Note also that if the three individuals are children in (47) – (49), we may deduce (17) *Three children came in* without any loss of information.

(47) John and Mary and Peter came in
(48) John and Mary came in, and Peter came in
(49) John, and Mary and Peter came in

The same applies to (44) and (17): there is no loss of information if we infer from the former to the latter. We simply meet here the property of being closed under union, which is the other property of (43). I think it is good to disconnect the use of conjunctions like *and* from all sorts of real world structures which slip in easily. The use of conjunctions in sentences like (44) – (49) says more about the mental organization of information by the speaker than it gives away from the structure of the event or events described.

Retrospectively, it is easy to see what is wrong with analyses based on a wrong axiom. For example, Roberts (1987b) goes a long way discussing distributivity without asking whether the opposition between a collective and distributive reading is correct for sentences like (50) – (52):

(50) Four men lifted a piano
(51) Bill, Pete, Hank and Dan lifted a piano
(52) Every man lifted a piano

She says that (50) and (51) are ambiguous between a collective reading (all together the same piano) and a distributive reading (each the same or a different piano). Roberts fails to see that her contention that "the group and the distributive reading entail different facts about the world" in which (50) and (51) are true, simply follows from her stipulation that there is a distinction between a collective and distributive reading. Suppose we would stipulate that the distributive reading of (51) should be broken up into D1 and D2, where D1 requires that the same piano be lifted, whereas D2 requires that each of the men lift a different piano. Such a stipulation would entail different facts about the world, because on the D1 reading it cannot be entailed that the four men lifted four different pianos, whereas on D2 this would be the case. In other words, any stipulation about readings allows different entailments. There is no reason to say that the collective reading of (50) would be "more different" from the distributive than D1 from D2. How could we establish this anyhow?

A conceptual reanalysis of distributivity in terms of the Boolean law in (43) involves a re-assessment on at least two issues:

(a) *the notion of atom.* It appears as if it must be relativized so as to mean 'minimal unit (or bottom element) at a certain (type-logical) level';
(b) *the notion of kolchoz-collectivity.* The question is whether it must be distinguished from existing collectiveness-notions like togetherness, joint intention, spatial-temporal proximity, etc.

Whatever the outcome of such a reassessment will be, it will lead to the view that the notions of atomicity and collectivity (in one of its senses) can no longer be opposed in an explanatory binary distinction. The concept of 'bottom element at a certain level' does not relate sensibly to any notion of collectivity, neither to the kolkhoz-notion nor to the other notions that are around. I will discuss point (a) in section 6, and point (b) in section 7.

6. BOTTOM ELEMENTS: INDIVIDUALS AND SETS

What do we gain conceptually by a change from Figure 2 to Figure 3? Let us first begin with a pragmatic answer to this question. One could grant me Figure 3, but one would say: "Okay, we have been merely rather sloppy in our terminology, so replace Figure 2 by Figure 3, add two terms and obtain something like Figure 4:

collective ← distributive → atomic

Figure 4

where *atomic* could be replaced by *individual*". Now there is a natural opposition between atomic and collective rather than between distributive and collective.

I think this would be wrong, because a continuing distinction between collectivity and atomicity (or individuality) would block a proper understanding of the way distributivity works at the ground level of quantification. In short, it is wrong to call *gather* a collective predicate just because it cannot take individuals; *gather* is as (Boolean) distributive as *sleep*, *walk*, etc. though at set level. This point can be clarified by considering sentences like (53) and (54) discussed in some detail in Van der Does (1992):

(53) The managers came together
(54) Four managers gathered
(55) The managers came in
(56) Four managers walked

They clearly differ from (55) and (56) by having predicates (*come together*, *gather*) requiring a plural NP. In Van der Does (1992), (53) and (54) does not have a distributive meaning, but he distinguishes between a collective reading and a neutral reading in which all sorts of subgathering may take place.

The naturalness of the new concept of Boolean distributivity shows up in a simple and also esthetically promising way: predicates like *come together* and *gather* are just as distributive as *come in* and *walk*, but their bottom elements (their "atoms") are sets containing at least two individuals. This could be obtained by simply characterizing the predicate *come together* lexically as holding irreflexively and symmetrically between any x and y involved in the relation 'come to the same place as ... ':[1]

(57) {{x,y}| x come to the same place as y ...}

That the predicates under this definition remain essentially distributive can be easily seen by giving the total range (58), where a, b, c and d are managers.

(58) top {{a,b,c,d}}
{{a,b}, {c,d}} {{a,c}, {b,d}} {{a,d}, {b,c}}
{{a}, {b,c,d}} {{b}, {a,c,d}} {{c}, {a,b,d}}
{{d}, {a,,b,c}}
atom {{a,b}, {a;c}, {a,d}, {b,c}, {b,d}, {c,d}}

[1] The dots indicate the place where more specific information could be given concerning intentions, such as 'to speak about something', or the like. Note also that unlike *meet*, the verbs *come together* or *gather* do not require a direct contact between any two persons involved in the predication. The irreflexivity may not come out very well in the loose description of the verbal meaning but it is given so as to exclude coming together with oneself.

This means that a sentence like (54) really ranges over all mathematically possible ways in which four managers satisfy the predicate *gather*. Note that (58) requires that (57) be slightly adapted because it is necessary to think of intermediate configurations like {{a}, {b,c,d}} to be interpreted as expressing that manager a came together with managers b, c and d. Accordingly, the definition (57) of *come together* might be recast in the form of pairs like {x,X}, where x is an individual and X is a set of individuals not including x, as in (59):

(59) $\{\{x_1,\ldots,x_n\} \mid x_1$ come to the same place as $x_2,\ldots,x_n \ldots\}$

By assuming that *come together* is a two-place relation between an individual and a set of one or more individuals, we account for the fact that *four managers came together* may be true for six different gatherings à deux, for all intermediate gatherings as well as for the sum total. As in the case of *come in* a speaker is completely left in the dark as to which configuration in (58) makes (54) true. All we know is that there is such a situation if (54) is true.

By these lexical and structural considerations it is not difficult to counter Van der Does' analysis of (53). His argument for adopting an unconstrained cover as in (26) and (27) is that he wants to make room for the following situation to which (53) should be allowed to apply. The managers came together in order to have a meeting in which they all were involved, but two of them, Ploeger (= a) and Timmer (= b), had a subgathering with one another simultaneously. We now analyze this subgathering in terms of Boolean distributivity. Given the "lump sum" information in (53), (59) allows us to deduce that Ploeger and Timmer stand in the come together-relation on the basis of (43) with as its bottom elements sets containing two individuals. This subgathering is exactly the same case as the child in (17) coming in several times because the law of distributivity (43) applies to any configuration of individual managers x_1 and x_{1+k} managers ($1 \leq k \leq n-1$).[1] The partition constraint ps on collections can be maintained for the same reasons as it could be maintained earlier, namely on the basis of the principle "Once Counted, Always Counted" given an equivalence relation with sets containing two elements as the bottom elements and structured on the basis of (59).[2]

The above considerations also shed some light on (1) *All the angles are 180°* because evidently the predicate *be 180°* can be interpreted as (roughly) $\{\langle x_1, x_2, x_3\rangle \mid x_1 + x_2 + x_3 = 180°\}$. It is clear that *be 180°* must be interpreted here as 'form the total of 180°', or '$x_1 + x_2 + x_3$ taken together are 180°', where be involves a +-operation. So, here again it is the predicate that has a specific meaning imposed on the set of angles of a triangle: it requires at least a set structure. Note that Jespersen in fact forced a triple-structure due to the fact that he used the NP *all the angles of a triangle*. Should he have used the sentence *These angles are 180°*, then two angles could have been combined. At any rate, it is clear that the predicate itself cannot apply to just one individual because it is taken in terms of a hidden +-operation.

For verbs like *come together* the minimal requirement for the individuals involved might be $\langle x,X\rangle$, with X containing at least one individual. But verbs like *to play trio*, or *to play a string quartet*, the requirement may be that $\{x_1,x_2,x_3\}$ or $\{x_1, \ldots x_4\}$ are the minimal atomic elements. Thus, sentences like:

(60) The participants of the Orlando festival played Beethoven's opus 74

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[1] Note that (53) has another interpretation which has not been captured yet. It may mean that the managers were involved in coming together with someone outside M. A solution would be to require that (59) is to be defined as leaving open which set $x_2 \ldots x_n$ come from.

[2] Van der Does' neutral reading seems to be compatible with the OCAC-principle.

require that there be at least four playing participants, because opus 74 is a string quartet. Suppose there are hundred quartet players at the festival. Then there is a combinatorial explosion of possible configurations because each of the individual players may have played with any other player (given certain restrictions about the instruments involved, of course). But note that a quartet may have been played by more than four players. In fact, there is no upper limit but the number of participants. So, (60) can be analyzed as giving the "lump sum", allowing all sorts of combinations based on distributivity (in the new sense) with quartets as bottom elements.

Theoretically, the verb *disperse* can be used for splitting up a set of individuals, say with m individuals. In sentences like (61)

(61) The herds dispersed

the use of the plural in (61) requires that this minimal level be multiplied. In other words, if there were k herds (61) must be about k times m individuals. It is important to distinguish sharply between what is said by (61) and what may be inferred from it. Sentence (61) *says* that a number of k herds fell apart into k individual herds. It is evident that the plural NP ranges here over a collection of herds, so there could be a principle saying that ⟦herd⟧ is to be treated as a collection of sets with a herd as a bottom element (at the set level that is). But one may argue that because the predicate remains applicable to each individual herd it can be *inferred* that each individual herd dispersed as well. If we would follow this line of thought, there would be a two-step interpretation of a process of complex dispersion. The question now is whether or not the inference falls under the law of distributivity, or not. If so, we would not be able to stop at the level at which a herd is the smallest element of the collection of herds. I think we may let distributivity do its job of connecting the lump sum (the herds presented as a collection) with the bottom elements (the atomic individuals making up a herd), on the condition that we recognize the transitional point. The need for such a point can be shown with the help of the following observations:

(62) The herds dispersed, but each herd remained intact
(63) ?The herds dispersed but neither of them remained intact
(64) The teams assembled, but each team got its own row of chairs
(65) ?The teams assembled, but each team had to disperse to do so

In (62) the first part says that the herds dispersed, whereas the continuation adds more specific information saying that contrary to what might be expected the distributivity law "stops" at the herds as bottom elements. Sentence (63) is somewhat odd, because the presupposition expressed by *but* runs counter to the rest of the continuation. The same applies to (64) and (65). From this one may derive that "all the way down-distributivity" is the default option, but that by their grammatical properties —the count noun herd (which in its singular form is a collective noun) is pluralized— sentences like (61) allow us to interrupt the law of distributivity at the turning point as shown in Figure 5 and to decide to stop the process of inferencing downwards by treating the collective noun in its singular form as an individual (in its literal sense, so to say). In other words, we do not assign (62) a distributive reading in which bottom elements of the herds are herds as against a collective reading in which we take the union over all the herds as in Roberts (1987b) and Landman (1989), but we consider both interpretations in terms of Boolean distributivity which may stop at the "turning point" where the grammatical singular happens to be a semantic plural.

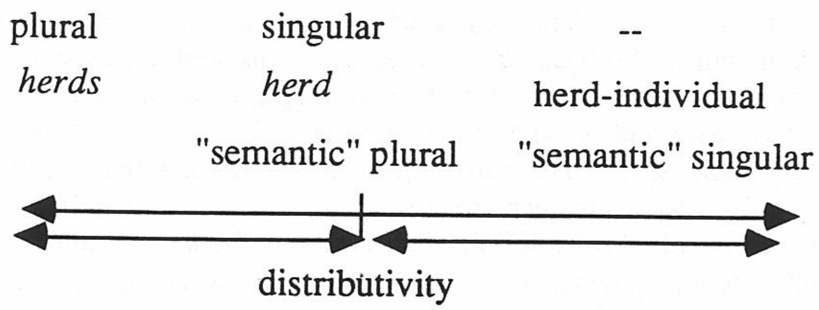

Figure 5

7. LIVING APART TOGETHER

It is now time to tackle the second point raised with respect to the reconceptualization of the collective notion: shouldn't we return to the old Jespersen kolkhoz-notion of collectivity by requiring that the predicate not apply to any one of the elements out of which the collection in question has been formed? This question has two aspects which deserve close attention: (i) is there a sensible opposite term for kolkhoz-collectivity, or any other forms of collectivity?; (ii) is collectivity itself a useful linguistic notion?

As far as I can see the only way to argue that a reading expressing kolkhoz-collectivity is to be structurally distinguished from Boolean distributivity, is the situation in which a predicate at least partly lexically favours a particular surplus-value to the kolkhoz-reading. Is this the case in (13) – (17)?

(13) All soldiers slept
(11) Two students walked
(17) Three children came in

The verbs *sleep*, *walk* and *came in* in (13) – (17) are Boolean-distributive at the first order individual level. Do these sentences have a kolkhoz-collective meaning? I would say that this depends on the force of our imagination. Under normal circumstances, (13) – (17) are not kolkhoz-collective and had better not require that they structurally have such a reading. On the other hand, in sentences like (14) – (24):

(14) Three men lifted the piano
(66) Three clowns threw a ball
(24) Three boys bought a boat

there might be sufficient reasons to distinguish a kolkhoz-collective reading. In (14), the men may have lifted the piano together but none of them may say that he lifted the piano all by himself and this could be relevant for distinguishing a reading distinct from a Boolean-distributive reading in which (14) covers a set of possible configurations in which the three men may have lifted the piano.[1] Likewise, sentences like (66) may pertain to a circus act where three clowns were involved in an act involving one ball which must be thrown as part of a collective act. Obviously, the need for kolkhoz-collectivity (each individual bought just a part of a boat, so to say) is certainly the strongest (or given standard western views on ownership the most natural

[1] In this connection, it is amazing to see that Landman (1989: 564) treats *carry a piano upstairs* as having a "normal collective reading", the distributive reading being marked. I fail to see why this predicate should be called (old) collective. Because pianos are normally heavy?

one) in (24), because joint ownership seems to be a well-established conceptual category. It differs clearly from a situation in which the boys each became the sole owner of a boat. The question for linguists is, of course, if this difference should be translated in a separate reading.

Whatever more can be said about these cases, one thing is clear: the nature of the predicate is quite central to the question of whether kolkhoz-collectivity shows up. That lexical considerations bear heavily on the issue can be illustrated by the observation that in (66) the whole situation in which the ball went from $clown_1$ to $clown_3$ via $clown_2$ can be called*throw a ball* because in the act the ball is only thrown if it reaches its end-goal but the predicate also applies to each of the two substretches ($clown_1$,$clown_2$) and ($clown_2$,$clown_3$). So is kolkhoz-collectivity a sensible linguistic concept? Before answering this question, let us try to see whether or not other forms of collectivity fare better, say collectivity based on a notion of spatio-temporal proximity? Consider situations described by the following sentences:

(67) John and Mary walked
(68) John and Mary walked together

For those who operate on the basis of the old collective/distributive distinction, (67) represents a case where *walked* is a mixed predicate or where *John and Mary* can be taken either collectively or distributively. In (68) *walk together* is taken as a collective predicate. But what about the following sentences?

(69) They ate some sandwiches together
(70) They listened together to their favorite music
(71) They drove together
(72) They bought everything they needed together

In (69), John ate three sandwiches and Mary ate two. They were together spatially, but each of them ate different sandwiches; in (70) John and Mary each listened on their walkman to their favorite music: John to Michael Jackson, Mary to Bruckner; in (71) John drove in a Peugeot and Mary drove in her Saab, but they went "en cohort", whereas in (72) John bought shaving cream, razors etc. with Mary as his adviser, whereas Mary bought her Saab with John as her advisor. It is clear that John and Mary lived apart together. Under the old collective/distributive opposition, distributivity is supposed to mean something like 'to act as its own agent, to satisfy the predicate individually' and collectivity something like 'to act together, to have no individual responsibility for the situation described'. Cases like (69) – (72) suffice to see that modern ways of life have overtaken a what turns out to be an essentially old-fashioned distinction. More in general, (69) – (72) seem to show that *together* is rather a modifier than a quantifier.

Lasersohn (1990) also recognizes that many sentences with *together* express a spatial-temporal proximity notion of collective action, but he adds these distinctions to the quantificational notion collectivity (which is not kolkhoz-collectivity). By this, new forms of ambiguity are added to the stock. In my view, the above considerations have made clear that there is no room for a notion of collective quantification as opposed to distributivity and this is inevitably the mould in which Lasersohn puts it. In this connection it is also relevant to point out that I disagree with his analysis of together in sentences like:

(73) John and Mary together lifted the piano
(74) John and Mary together lifted their piano

Lasersohn assigns to (73) the reading in John and Mary collectively lifted the piano. But sentences like (74) show that people can lift different pianos together. The togetherness does not express itself quantificationally in the first place, though it might be implied by spatial proximity, contextual knowledge about the weight of pianos, etc. If one insists on a counterexample using (73) itself, think of John and Mary acting as a couple in a circus having to do exactly parallel tasks on their own, among which lifting a (foamy or a small) piano.[1] So, they each have to pour water in a barrel, to sit on the back of a horse, to throw a ball, all as part of an act which consists of doing things strictly parallel. Now, one may easily say (73) with adverbials like *at that moment*, *at exactly the same moment*, *easily*, *correctly*, *swiftly*, etc.[2] So, again we see that definitions are given on the basis of accepting a distinction rather than proing it to be right.

Before continuing, let us first have a look at the collectivity coin from the point of view of the alleged (old) distributivity of *each*, *every*, etc. In general any opposition between collectivity and distributivity involving agency remains as obscure as the notion of agency itself. This can be illustrated by sentences like:

(75) The tyrant gave each athlete a medal

In (75), it is possible to think of a situation in which all the medals were given at the exactly same moment in some stadium: during a mass meeting and neatly organized each boy gets a medal from some representative of the tyrant at a given sign. Likewise, (76) pertain to one email message spread around through the world by someone:

(76) She sent an email to every linguist working on anaphoricity

This message reached every linguist at the same time because it was addressed by a collective mailing facility. So, there is one event which actualizes in a multitude of token-events.[3] So, one might argue that *each* and *every* can be used in many contexts in which it is clear that the predicate applies to something jointly. What I would like to make clear, is that *each* and *every* of course have their contribution to make to the meaning of NPs, VPs or sentences, but that their role is less quantificational than suggested in the literature. For example, (75) and (76) may be analyzed as giving simply information about the minimum level of the bottom elements, as it would in the case of

(77) The tyrant gave a medal to each pair of athletes
(78) She sent an email to every group of linguists working on anaphoricity

That is, (77) and (78) do not give information about a spatio-temporal ordering in which each pair or group received something at a different place or time, it just presents the law of distributivity from the bottom side, so to speak. It starts with the bottom elements and by (43) one may effectuate closure under union up to the sum total of pairs and groups. In other words, a language may use different means to express Boolean distributivity: lump sum information and bottom information. But they are two sides of the same coin and there is no need to assign to different readings to it.

For the present discussion, four lexical categories seem to be important: (a) nouns; (b) verbs; (c) adjectives, and (d) determiners. Languages like English have collective nouns like *herd*, *committee*, etc. most of which can be pluralized themselves. So, they have two sorts of behaviour: in their singular form they require a set level predicate, in their plural forms (e.g. *ten*

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[1] As in (70), the use of *their* complicates the discussion (cf. also Link 1987), because the predicate 'their ...' should never be able to apply to individuals. Yet it does, perhaps due to the distributivity law.
[2] For other problems with Lasersohn's treatment of together, see Schwarzschild (1992).
[3] This is the same case as *For hours Den Uyl handed the labour badge to congressgoers* discussed in detail in Verkuyl (1976).

herds crossed the river) they behave like regular count nouns. Verbs have a similar distinction: *gather* requires a set level from its singular argument, but it may behave like regular verbs like *walk* if they occur with a plural argument. Adjectives like *collective*, *joint*, etc. require clearly a set level if they modify a singular NP, but here again they behave like non-collective adjectives as soon as the NP is plural. The same applies mutatis mutandis to modifying adverbs, like *together*, *jointly*, etc.

Given the standard format $D_E(A,B)$, where $A = [\![N]\!]$ and $B = [\![VP]\!]$, the above considerations with respect to the interaction between nouns and verbs in a predication seem to carry over to determiners, as they regard the interaction between the external argument N and the VP which is determined by Det. However, in general, determiners seem to be neutral with respect to restrictions between N and VP: their only demand is that the distributivity law (43) operates as it should do. They require agreement, of course, but this is independent of the question of whether the bottom elements are individuals or sets. In this connection, it is relevant to observe that the lexical categories of verbs and nouns each have a marked subcategory which require sets as bottom elements, whereas the unmarked categories allow both individuals and sets. For determiners this is different: if they are marked, they mark the bottom side of (43). In other words, there are no determiners in English and in Dutch which behave like nouns and verbs by requiring set level predicates only. Here the syntax of agreement clearly interferes: some determiners require a plural predicate (*all*, *many*), some require a singular predicate (*each*, *every*), whereas others are neutral. But these requirements do not translate into semantically relevant distinctions.[1]

On the other hand, a standard model is construed from its individuals, so we may expect that at its "bottom" there are effective ways of providing specific information, leaving intact the inferential information by respecting closure under union. *Each* and *every* make sure, on top of the regular Boolean distributivity, that speakers "enter" (43) via the bottom elements rather than via lump sum information. But recall that *Each child came in* entails that *all children came in*, and conversely. Note in passing that from *Each twin child came* in one may infer *All twin children came in*, but not *All children came in.* In this connection it is also interesting to observe the following:

(79) Each pair gathered
(80) They each gathered
(81) The groups gathered each
(82) *The police gathered each

Sentence (79) says that the bottom elements of the predicate *gather* involved in the predication, were pairs. Note that it is not excluded at all that each of the gathering pairs were involved in the same meeting: one simply has to think of a situation in which someone says (79) after having looked at some list and having observed that each pair mentioned on it was involved in the gathering. Note also, that in this context (80) would be perfectly normal to say, whereas it would be unacceptable for a situation in which the foreign ministers of the European community gathered with each other. Also (81) and (82) indicate that *each* is a bottom-marker rather than a quantifier because (81) shows that *each* may pertain to a set, whereas (82) shows that this cannot be an arbitrary subset of the set denoted by *the police*.

Summarizing, we may observe that the role of *each* and *every* in English is to give information about the range of the distributivity law (43), in particular as to the nature of its bottom-elements. Its "top" (the left-hand side) is always given in a lump sum way (*all participants*, *three*

1 Hermann Paul (1920) points out that in the 18th century the German *jeder* still had a plural form *jede* whereas at that time the plural form *alle* also had a singular (masculine) form *aller*.

boys, *many players*, etc.), hiding a lot of possible set theoretical structure —the players may be trio players, the participants may be boards of managers, etc. I think there is a deep asymmetry involved: lump sum information is often the easy and handy way to communicate, so languages will tend to see this as the unmarked case and they will not develop means to signal it. I do not exclude that some languages will have developed them but the Germanic and Romance languages do not have them.

8. THE π-FUNCTION

In Verkuyl (1988; to appear) it was proposed to analyze the predication of the form NP_1 $[_{VP}$ V $NP_2]$ in terms of a function π which assigns to each of the individual members of the NP_1-denotation a set of pairs where each pair consists of an index and a subset of the denotation of the internal argument NP_2. This function π: $\mathbf{D_e} \rightarrow (\mathbf{N} \rightarrow \mathbf{D_L})$ is defined as follows:

(83) $x \mapsto \ell$, where $\ell = \{\langle i,p\rangle \mid [\![AT(p)(x)]\!]_{M,i}=1\}$

where **N** is taken as a set of indices representing intervals, $\mathbf{D_L} = [\![NP_2]\!]$ is the domain of (mentally conceived) "spatial" coordinates p, and $\ell \in \mathbf{D_L}^{\mathbf{N}}$. AT is a two place relation between x and p: it determines x's position p dependent on (numerical) indices. The NP_2-denotation [[five boats]] itself is the union of the function values $\ell(i)$. The range of ℓ is finite if $\mathbf{D_L}$ is finite.[1] Given (83), one may picture out one of the possible event-configurations described by (84) in terms of the resulting path-structure as illustrated in Figure 6.

(84) A boy bought five boats

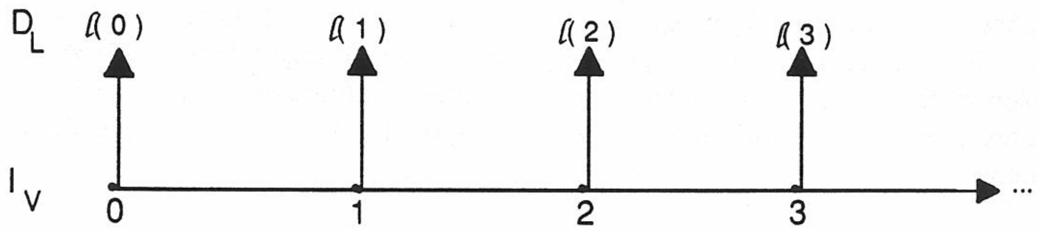

Figure 6

The thematic equivalence relation partitioning the set W of five boats is '*counting as* being involved at the same index'. This is partly expressed by ps in $\exists Q$psW in the atemporal represen-

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[1] A spatial coordinate is a point in one of the so-called "semantic fields", i.e. in a set of semantic values ranging over mentally represented spatial positions, possession, identity, circumstance. The formula defining π can be seen as a way to define localism in terms of standard modeltheoretic tools. Loosely speaking *to eat five sandwiches* can be seen as "going through a set of sandwiches". This way of speaking can be formalized into the standard set theoretical form Figure 6 represents exactly this translation: the NP_2-denotation $\mathbf{D_L}$ taken as a collection of sets is structured along an axis which is well-ordered by its isomorphism with **N** (and at a different conceptual level with **R**). Now, in *fly to three cities*, or *eat five sandwiches* or *buy five boats* the NPs can each be seen as providing a co-domain $\mathbf{D_L}$ of a function which incrementally builds up a relation between ordered indices and subsets of D_L. In this way, the aspectually relevant properties of sentences containing these VPs can be accounted for modeltheoretically maintaining the valuable mentalistic insights of the localistic framework. In Verkuyl (to appear) it is argued that tense is one of the ways to "get from" **N** into **R** (i.e. into real time). So, in the system there are non-linguistic functions connecting **N** and **R**. The idea behind the formalism is that speakers and hearers use representatives for real world entities and structures they speak about and that these representatives are made discrete mentally, without having to bother about the underlying real world structure. Hence they can be treated as belonging to **N**.

tation (85).

(85) $\exists Z[Z \subseteq [\![boy]\!] \wedge |Z|=1 \wedge \exists P \text{ps} Z[P=\{V \cap [\![boy]\!] | \exists W[W \subseteq [\![boat]\!]$
$\wedge |W|=5 \wedge \exists Q \text{ps} W[Q= \ldots]]\}]]$

Recall that $\exists Q$psW in (85) expresses that Figure 6 represents just one of the situations making (84) true, i.e. the one in which he bought five boats at three successive "counting points". The existential quantifiers captures all other configurations as well. I shall not go into the full temporal extension of (85) here because there a number of type-logical adaptations must be made, but it is easy to understand that $\exists W$ will have to be replaced by information expressing something like 'there is an indexed family of sets $\{W_i\}_{i \in N} \ldots$' (recall that an indexed family of sets is a function taking indices yielding a collection of sets; cf. Verkuyl to appear).

The function π can be called a *participancy* function because π determines the way in which the members of the NP_1-denotation participate in the predication. This is motivated by the extensional nature of the subject NP_1-position: π makes sure that each *individual* belonging to the NP_{ext}-denotation be assigned its own unique image (its own Path, so to say), as in (86), where the function π is spelled out for each x.

(86) $x_1 \mapsto \ell_1: \mathbf{N} \rightarrow \mathbf{D_L}$
$x_2 \mapsto \ell_2: \mathbf{N} \rightarrow \mathbf{D_L}$
$x_3 \mapsto \ell_3: \mathbf{N} \rightarrow \mathbf{D_L}$
...

Verkuyl (1988) proposed two variants of the function π: an injective function π_i and a constant function π_c. When π is an injection, then for all i,j, $x_i \neq x_j \Rightarrow \ell_i \neq \ell_j$. When π is a constant function, then for all i,j, $x_i \neq x_j \Rightarrow \ell_i = \ell_j$.

An analysis based on (86) makes it possible to vary over members of $\mathbf{N}$ and $\mathbf{D_L}$. Thus, the function value $<1,table_1> \neq <1,table_2> \neq <2,table_1>$. This enlarged degree of freedom solves the problem of there being just two tables in (16) *Three men lifted two tables*, as exemplified by (87), where I will write natural numbers as subscripts of indices i, j and k in order to distinguish them properly:

(87) $man_1 \mapsto \{<i_1,table_1>, <i_2,table_2>\}$
$man_2 \mapsto \{<j_1,table_1,>, <j_2,table_2>\}$
$man_3 \mapsto \{<i_1,table_2,>, <i_2,table_1>\}$

This configuration which is just one of many allowed by (20) —given the adaptation with indices— meets the conditions of π_i because for each individual man x in the NP domain, there is a different unique function value $\ell(x)$. The configuration (88), abbreviated as (89) is yielded by π_c as one of a variety of interpretations in which all boys relate to a constant function value:

(88) $man_1 \mapsto \{<i_1,table_1>, <i_2,table_2>\}$
$man_2 \mapsto \{<i_1,table_1>, <i_2,table_2>\}$
$man_3 \mapsto \{<i_1,table_1>, <i_2,table_2>\}$

(89) $man_{1,2,3} \mapsto \{<i_1,table_1>, <i_2,table_2>\}$

The function π also covers cases like (90)

(90) Three boys bought a boat

where (91) gives π as a constant function, and two of a larger set of possible configurations in (92) as an injection.

(91)	$boy_{1,2,3} \mapsto \{\langle i_1, boat_1\rangle\}$	
(92)	$boy_1 \mapsto \{\langle i_1, boat_1\rangle\}$	$boy_1 \mapsto \{\langle i_1, boat_1\rangle\}$
	$boy_2 \mapsto \{\langle i_1, boat_2\rangle\}$	$boy_2 \mapsto \{\langle i_2, boat_1\rangle\}$
	$boy_3 \mapsto \{\langle i_1, boat_3\rangle\}$	$boy_3 \mapsto \{\langle i_3, boat_1\rangle\}$

At this point, it is rather tempting to interpret π_c, i.e. π taken as the constant function, as the way to express kolkhoz-collectivity, which can now be defined as the situation in which members of an NP-denotation lack an individual path. If we interpret (90) in this way, it can also be explained why it misses a collective interpretation where there is one boat which is bought by three boys such that they became its individual owner. The only way to approach such an interpretation is in fact the right-hand side of (92), but here there is a clear succession: they must have sold it to one another. The left-hand side gives a sense of (spatio-)temporal proximity, but it is not kolkhoz-collective.

As to (91) and (89), we might even defend the position that they may very well represent the kolkhoz-collective interpretation. Note that in the present analysis one may take the possibility for kolkhoz-collectivity to occur as a marked form of π.[1] That is, π_i is the default form of π, and π_c can be considered as marked given the predicate, e.g. the presence of plus-operation as in (1). If we continue to think along these lines, it becomes attractive to think of modifiers like *together* as being able to get from the injection to the constant function, although it also might work on the indices. These consequences will not be investigated in the present paper.

The π-function also solves the rest of the D-mark problem. Lønning's problem with the asymmetry of representation (23) was that it predicts that the three soldiers in *Three men received 100 DM* could receive 200 DM. This problem can be solved now easily by (93).

(93) $\exists Z[Z \subseteq [\![soldier]\!] \wedge |Z|=3 \wedge \exists P ps Z[P=AT([\![soldier]\!]) \cap \{V | \exists W[W \subseteq [\![DM]\!] \wedge |W|=200 \wedge \exists Q ps W[Q=\{U \cap [\![DM]\!] | [\![receive]\!](U)(V)\}]]\}]]$

Here the presence of the π-function is made visible by requiring that P (its domain) be structured so as to contains singletons. These are the arguments for π. It is not hard to think of a general requirement on representations like (93) defining π as an injection (i.e. the indices on W should be different or the sets belonging to the family of sets Q must be different), unless we wish to take π as a (marked) constant function. This prevents the three soldiers from receiving just the total sum of 200 DM.

The π-function is defined for two-place predicates, because there the asymmetrical distinction between external and internal argument shows up. In Verkuyl (to appear) a subset of the one-place predicates is defined in terms of having an internal argument but lacking an external argument (unaccusatives), whereas the other one-place predicates do have an external argument. In this, I am simply following a now near linguistic standard practice. The difference between three sorts of verbs can be (roughly) expressed as in (94) – (96):

(94)	$\lambda X \lambda i \lambda Y [\![V]\!](i)(Y)(X)$	transitive
(95)	$\lambda X \lambda i [\![V]\!](i)(X)$	unergative
(96)	$\lambda i \lambda Y [\![V]\!](i)(Y)$	unaccusative

X is the variable for the external argument, Y is the internal argument variable of the verb V and i is a variable over indices associated with the sets Y forming the internal argument denotation: in terms of Figure 6 for each i, $Y = \ell(i)$. In terms of the π-function: π applied to X yields for k

[1] This could make π not-ambiguous along the lines of Atlas (1989).

indices: $\{<1,Y_1>, \ldots <k,Y_n>\}$.[1]

Now, the question is what π does in (95) and (96)? The function ℓ in (83) is operative in unaccusative verbs like *die*, *arrive*, *awake*, *rise*, *grow*, *succeed*, etc., but here there is no x around for π to apply, whereas in unergative verbs like *work*, *play*, *laugh*, *dance*, *cough*, etc. the domain of π contains the proper elements but now ℓ is absent of course So, by the absence of a collection of sets Y to "go through", no "path structure" for any x can be built up. Verkuyl (to appear) did not develop a formalism for the π- or ℓ-relations between NP and V in intransitive sentences of the form NP $[_{VP}$ V$]$, but it is predicted by the use of the π-function for transitive sentences that the verbs in (95) and (96) at least should differ with respect to the opposition between the constant and the injective function, because there is no way to yield such a distinction. Indeed, it appears to be the case that there can be no kolkhoz-collectivity at all for verbs in the category (95), but verbs like *win* may be construed such that they express a kolkhoz-collective victory as in the 4×100 meter races. It should be observed though that this form of collectivity seems to be an exception for verbs of the category (96) and one might even argue that *win* is taken here in its two-place interpretation (*win the 400 meter*). I tend to think so, because it sets (95) and (96) apart from (94) on the ground that for them the π-function does not operate or does not operate on external argument singletons. If it is true that genuine kolkhoz-collectivity comes in only at the level of two- or higher place predicates, then this fact would constitute another argument against the collective/distributive opposition, because Boolean distributivity operates for all predicates.

[1] The representations of the three categories is somewhat simplified here, because I want to restrict the information to what is needed for making the point at issue. Perhaps it is necessary to say that in Verkuyl (to appear) it is argued that the three representations form frames in which verb stems V are to be inserted (non-compositionally) so as to form the lowest level syntactic units. Thus, the verb stem *walk* can be inserted into the transitive frame (accounting for its transitive use) as well into the unergative frame (accounting for its intransitive use). We have to assume for the unaccusatives that some transformation puts the internal argument into the subject position. But as said, this is practically standard nowadays.

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Towards a dynamic and compositional treatment of temporal expressions

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This paper presents a format for the representation and interpretation of temporal relations in texts. It covers the same phenomena as Discourse Representation Theory, but it is more in line with the principle of compositionality: the temporal structure of a text is described as a function of the meanings of the individual clauses and the temporal expressions they contain, rather than the other way round.
The format is highly modular: it has a compositional core consisting of two modules (tense and aspect) and a dynamic scheme for the interpretation of cross-clausal relations, as expressed by temporal anaphora and the like. The format will be presented in sections 4 and 5, and compared with the DRT treatment in section 6. The first three sections prepare the ground with a discussion of the notions "time of reference" and "point of perspective", and with an overview of the main surface markers of temporal relations, i.e. the grammaticalised forms of tense and aspect.

1. The time of reference

The notion of "reference time" was first introduced by Hans Reichenbach,and then adopted by many linguists and logicians. As most other popular terms it has come to mean a number of different things, depending on the system in which it functions. Two of these systems will be presented and compared: the original Reichenbach one (1.1) and the one of Discourse Representation Theory (1.2). Taking into account some of the criticisms which the latter has recently elicited I will then define the role which the reference time plays in my treatment (1.3).

1.1. In Reichenbach 1947 the time of reference serves three different functions.
The first, and probably the most familiar, concerns the semantic analysis of the grammaticalised forms of tense and aspect. Reichenbach claimed that those forms cannot simply be analysed as relations between a time of event (E) and a time of speech (S). Indeed, taking a linearly ordered set of time points as a model, there are just three possible relations between E and S: E is before S (E<S), E is after S (E>S) and E coincides with S (E=S). It follows that the English past tenses, for instance, which include a.o. the simple past, the pluperfect, the present perfect and the past progressive, will be analysed as E<S, thus ignoring the fact that they have mutually distinct meanings.

Reichenbach's proposal to make use of a point of reference (R), intermediating between E and S, enhances the expressive power of the formalism: instead of three relations between E and S, he uses three relations between R and S, plus three relations between E and R, resulting in nine different combinations. Analysing the past tenses in terms of both relations, Reichenbach is able to make the required differentiations:

Simple Past	R<S	E=R	R,E —— S
Present Perfect	R=S	E<R	E —— S,R
Pluperfect	R<S	E<R	E —— R —— S

The line stands for precedence, the comma for coincidence

The further distinction between the simple past and the past progressive is made by allowing E to be either a moment or a period of some length:

$$\text{Past Progressive} \quad R<S \quad E\supset R \quad \overbrace{R}^{E}\text{———}S$$

The second function of the time of reference is to serve as the denotatum of time adverbials, like "now", "yesterday", "in 1678", "when John came", etc. These adverbials cannot generally be interpreted as specifications of the time of event. In

(1) at 5 o'clock he had already disappeared

the time denoted by "at 5 o'clock" is not the time of the disappearance (E) nor the time of speech (S), but rather a time at which the disappearance had already taken place. Given the analysis of the pluperfect it is obvious to treat it as a specification of the intervening time of reference. Similarly, in

(2) at 5 o'clock they were all dancing

the adverbial does not denote the time of dancing, which is a period of some length, but rather an instant which is included in the dancing time, and given the analysis of the past progressive the obvious candidate for being this instant is again the time of reference.

The third function, and the one which will interest us most in the rest of the paper, concerns the interpretation of sequences of sentences in discourse. In the following piece of text, taken from W. Somerset Maugham's "Of Human Bondage" and discussed in Reichenbach 1947, we can identify six events E_i [1]:

(3) But Philip ceased to think of her for a moment after he had settled down in his carriage. He thought only of the future. He had written to Mrs. Otter, the massière to whom Hayward had given him an introduction, and had in his pocket an invitation to tea the following day.

E_1 = Philip cease to think of her

E_2 = Philip settle down in his carriage

E_3 = Philip think only of the future

E_4 = Philip write to Mrs. Otter, the massière

E_5 = Hayward give Philip an introduction to Mrs. Otter

E_6 = Philip have an invitation to tea in his pocket

The clauses with a simple past are analysed as R,E—S, and those with a pluperfect as E—R—S. This information from the tenses does not -in itself- say anything about the relations between the times of event of the different clauses; indeed, even if we would accept the rather obvious stipulation that the time of speech is the same for the whole fragment, there is nothing in the analysis of the simple past and the pluperfect which prevents us from deriving a representation like

(4)
$$\begin{array}{lccc} R_3,E_3 & \text{———————} & & S \\ & E_4 \text{——} & R_4 \text{——} & S \end{array}$$

in which Philip's writing to Mrs. Otter (E_4) takes place after the thinking of his future (E_3). This is not the way in which (3) is interpreted (or intended), though.

In order to arrive at a more plausible interpretation Reichenbach introduces the principle of the permanence of the reference point. It requires that the time of reference be the same for the whole fragment, and thus leads to analysis:

(5)
$$\begin{array}{rll}
 & R_1,E_1 & \text{—}\ S \\
E_2\ \text{—} & R_2 & \text{———}\ S \\
 & R_3,E_3 & \text{—}\ S \\
E_4\ \text{—} & R_4 & \text{———}\ S \\
E_5\ \text{—} & R_5 & \text{———}\ S \\
 & R_6,E_6 & \text{—}\ S
\end{array}$$

The events 1, 3 and 6 are claimed to hold at the same time: Philip's ceasing to think of her, his thinking of the future and his having an invitation to tea all hold at the permanent reference time R_i. The events 2, 4 and 5, which are described in clauses with a pluperfect, precede this time of reference, but there is no information about their mutual order [2].

The principle of the permanence of the reference point is not without exceptions: if there is a time adverbial which explicitly introduces another reference point than the one which is contextually given, then the one given by the adverbial gets priority. In

(6) He was healthier when I saw him than he is now

the time of reference of the first two clauses is in the past, but the one of the third clause, specified by "now", is in the present:

(7)
$$\begin{array}{ll}
R_1,E_1\ \text{———} & S \\
R_2,E_2\ \text{———} & S \\
 & S,R_3,E_3
\end{array}$$

Reichenbach calls this the positional use of the reference point.

1.2. Of the three functions which the time of reference has in Reichenbach's work, DRT concentrates on the third, i.e. on the role of the point of reference in the interpretation of texts.

Its role in the semantic analysis of the individual forms of tense and aspect is secondary. The distinction between the passé simple and the imparfait, for instance, is not described in terms of the contributions which they make to the truth conditions of individual sentences, but rather in terms of the different contributions which they make to the interpretation of texts: "The choice of the tense form depends on the function that the sentence in which it occurs has in a text. In other words, the factors which determine the use of imparfait and passé simple can only be explained at the level of discourse representation." [Kamp & Rohrer 1983, 253]

Indeed, whereas it seems rather hard to pin down the semantic difference between (8) and (9)

(8) Marie téléphonait

(9) Marie téléphona

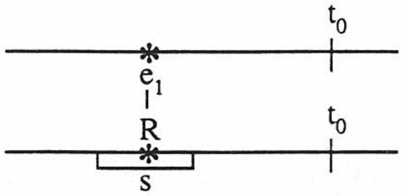
it is easy to describe the difference between (10) and (11)

(10) Quand Pierre entra, Marie téléphonait

(11) Quand Pierre entra, Marie téléphona

In (10) Marie was already at the phone when Pierre entered, whereas in (11) she started the phone call after Pierre entered. With t_0 as the time of utterance, e_1 as the event of Pierre's entering and S as the state of Marie's being at the phone, the temporal relations in (10) are as follows:

(12)

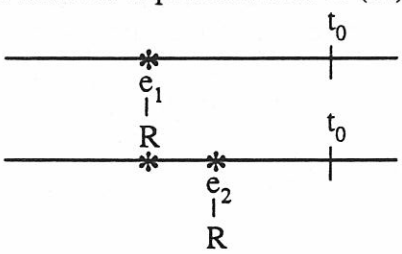


$e_1<t_0$
$R:=e_1$
$s<t_0 \quad s\supset R$

The point of reference is provided by the event of the first clause ($R:=e_1$) and serves as a starting point for the interpretation of the second clause. Since the latter is in the imparfait it expresses a state (S) which precedes t_0 and which includes the point of reference, and hence also e_1.

Compare this with the representation of (11):

(13)



$e_1<t_0$
$R:=e_1$
$e_2<t_0 \quad e_2>R$
$R:=e_2$

In this case, the second clause is in the passé simple and therefore introduces a second event (e_2), which follows the point of reference (R) and hence also e_1.

A second difference is that e_2 in (11) provides the point of reference for the interpretation of the next clause ($R:=e_2$), whereas the state in (12) does not provide a new point of reference, so that the next clause will be interpreted with respect to e_1.

Starting from this scheme the meaning of a tense -defined as its contribution to the interpretation of a text- consists of three parts: (1) it introduces a state or an event in the discourse representation structure (DRS); (2) it locates this state or event with respect to the time of speech; (3) it defines the relation between the event or state and the current time of reference.

The imparfait, for instance, introduces a state (s_i), and locates it before the time of speech ($s_i<t_0$) and around the current time of reference ($s_i\supset R$). The passé simple introduces an event (e_i), and locates it before the time of speech ($e_i<t_0$). As for its relation with R, there are several possibilities: in (11) the event in the second clause follows R, but in

(14) Marie chanta et Pierre l'accompagna au piano

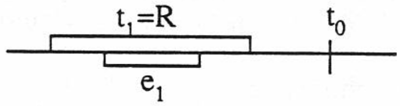
it coincides with R, since Pierre's performance on the piano coincides with Marie's singing, and in

(15) L'année dernière Jean escalada le Cervin. Le premier jour il monta jusqu'à la cabane H.

it forms part of R: the climbing to hut H is part of the climbing of the Cervin. It follows that the constraint on the relation with R has to be rather weak; in Kamp & Rohrer 1983 it is proposed that the event introduced by the passé simple should not entirely precede R: $\sim e_i < R$. Notice that this allows for a range of possible relations, including the one which was used for the imparfait ! The only difference between both forms, then, is that the passé simple introduces an event and the imparfait a state.

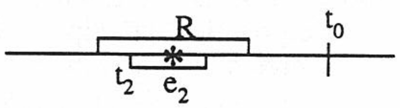
The role of the reference time in the analysis of the time adverbials is a complex matter in DRT. Time adverbials are treated as specifiers of temporal location times and the latter are introduced in DRS as intervals t_i, for $i>0$. Whether these location times serve as reference times depends on many factors. For instance, the adverbial in the first clause of (15), "l'année dernière", specifies an interval which provides the time of reference for the interpretation of the first clause:

(16)



but the time of reference for the second clause is the event described in the first clause (R:=e_1), and not the time adverbial, "le premier jour"; the latter specifies an interval t_2 without any special role in the discourse interpretation:

(17)

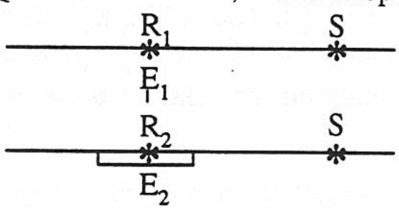


There is a lot more to be said about the treatment of time adverbials in DRT (cf. sections 2 and 6). At this point, however, it suffices to observe that time adverbials do not necessarily specify R.

1.3. The role which Reichenbach attributes to the time of reference in the interpretation of texts is quite different from the role it has in DRT. To appreciate the differences compare the DRT analyses given in (12) and (13) with the ones which Reichenbach would provide for the same sentences:

(10) Quand Pierre entra, Marie téléphonait

(18)



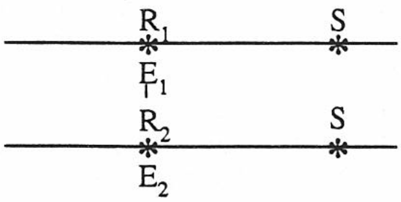
$R_1<S$ $E_1=R_1$

$R_2=R_1$ (permanence of R)

$R_2<S$ $E_2 \sqsupset R_2$

The relation between E_1 and E_2 in (18) is the same as between e_1 and S in (12): in both cases Marie's phoning temporally includes Pierre's entering.

(11) Quand Pierre entra, Marie téléphona

(19) 

$R_1 < S \quad E_1 = R_1$

$R_2 = R_1$ (permanence of R)

$R_2 < S \quad E_2 = R_2$

Here, the relation between E_1 and E_2 in (19) is different from the one between e_1 and e_2 in (13): whereas the former predicts that Marie's phone call is simultaneous with Pierre's entering ($E_2=E_1$), the latter predicts that Marie called after Pierre had entered ($e_2>e_1$).

In order to get the same result in Reichenbach's framework one could loosen the constraint on the relation between E and R.

Instead of requiring it to be identical, one could allow E to follow R, as in DRT. Notice, however, that the resulting analysis of the passé simple, R<S and E>R, is the one which Reichenbach employs for the future-in-the-past, i.e. for the conditionnel I. Assigning this meaning to the passé simple would amount to claiming that (11) is synonymous with

(20) Quand Pierre entra, Marie téléphonerait

which it is not.

Another way out would be to loosen the constraint of the permanence of the reference point, allowing the reference point to move forward, even if there is no time adverbial which triggers this move. This is, in essence, the solution proposed in Dowty's temporal discourse interpretation principle: "Given a sequence of sentences S_1, S_2, ..., S_n to be interpreted as a narrative discourse, the reference time of each sentence S_i (for i such that $1<i\leq n$) is interpreted to be:

(a) a time consistent with the definite time adverbials in S_i, if there are any

(b) otherwise, a time which immediately follows the reference time of the previous sentence S_{i-1}." [Dowty 1986, 45]

Reichenbach's positional use of the reference point is subsumed under (a), and the permanence of the reference point is now replaced by a systematic forward movement (b), at least for narrative discourse [3].

An attractive property of this proposal is that it allows for a uniform treatment of the passé simple: its meaning is constant ($R_i<S$ and $E_i=R_i$), and whether E_i follows E_{i-1} in a given piece of text depends on the relation between R_i and R_{i-1}, and not on the relation between E_i and R_i.

DRT does not allow for such a uniform treatment of the tense. Indeed, the contribution of the passé simple to the interpretation of (11) is different from the one in (14) and (15): $R>e_i$ vs. $R=e_i$ vs. $R\supset e_i$. One way to accomodate this variation is to postulate a very broad meaning for the passé simple, as Kamp & Rohrer do, but this turns out to be so broad that it includes the one of the imparfait.

Another way to accomodate the facts in DRT would be to claim that the time of reference is not identical to a previous event ($R{:=}e_{i-1}$), but rather follows it by a short distance ($e_{i-1}<R$). This alternative is the one adopted in Hinrichs 1986 and Partee 1984: "We can generalize the idea that in the simple linear case an event-clause moves the narrative forward by bringing in a new reference time that is 'just after' the given event." [Partee 1984, 256] Applying this scheme to the passé simple we could assign it a rather specific meaning, such as $e_i \subseteq R$, and achieve the effect of forward movement by locating R after e_{i-1}.

As a result we now have four ways of dealing with fragments like (11). There is the original Reichenbach treatment, which does not get the facts right, and there is the original DRT treatment, which is less felicitous from a methodological point of view. In between, there are the treatments of Dowty and Partee. Both manage to get the facts right without giving up the assumption that the contribution of the tense is constant, but they achieve this in different ways. Whereas Dowty defines the time of reference with respect to the time of reference of a previous clause, Hinrichs and Partee define it with respect to a previous event, as in DRT.

It follows that the latter make the forward movement of the time of reference dependent on the aspectual class of the previous clause: if it is an event, the time of reference moves; if it is a state, the time of reference does not move.

This reliance on the state/event distinction has been criticised in Dowty 1986. Since it touches on the very core of DRT, it is worth examining in some detail.

One of the basic claims of DRT is that the interpretation of a text is more than the sum of the interpretations of its sentences. More specifically, it treats the meaning of the individual sentences as a function of the meaning of the text, rather than the other way round. Formalising this holistic perspective on meaning, DRT postpones the interpretation of each individual sentence till after the construction of a discourse representation for the text as a whole. The treatment of the distinction between passé simple and imparfait provides a good illustration of this strategy.

Now, if the rules for the construction of DRS refer to the aspectual class of the individual sentences, and if the latter is not a syntactic but rather a semantic property, as has been argued by most linguists who have investigated the matter (cf. Mourelatos 1978, Dowty 1979, a.o.), then it follows that the individual sentences should be assigned a model-theoretic interpretation before the rules of DRS construal are applied. But this contradicts the basic DRT assumption. In Dowty's words: "If the compositional model-theoretic interpretation of the sentences in a discourse is determined only after a discourse representation has been constructed (as Kamp proposes), and if it is only in the model-theoretic interpretation that the aspectual class of a sentence is fully apparent (as I am arguing), then how can aspectual class have an effect on how the temporal relationships between sentences are represented in the discourse representation ?" [Dowty 1986, 40]

As an alternative to DRT's holistic view on sentence meaning, Dowty pleads for a treatment which is more in line with the principle of compositionality: "... it seems that the temporal relationships among sentences in a discourse depends on the prior determination of the semantics of the individual sentences, contrary to Kamp's proposal as I understand it." [ibid.]

Following Dowty's suggestion I will explore an alternative in which the contribution of the temporal expressions to the meaning of a text is described as a function of their contribution to the meanings of individual sentences.

For the grammaticalised forms of tense and aspect, this implies that their meanings should be properly differentiated at the level of the sentence, or -rather- the clause.

For the time adverbials, it implies that their contribution to the meaning of a clause should be constant. The DRT treatment, in which they are treated as specifying the time of reference in some cases and not in others, is less attractive from this point of view than the treatments in which they invariably specify R. Examples of the latter are not only the ones proposed by Reichenbach and Dowty, but also the more DRT oriented treatments of Hinrichs and Partee: "The adverb, whether clausal or phrasal, provides a descriptive characterisation of the new reference time; it may identify it completely ('at 3 o'clock on June 12') or simply put bounds on it, as with frame adverbials like 'in June'." [Partee 1984, 257]

In both cases, i.e. the analysis of the grammaticalised forms of tense and aspect, and the treatment of the time adverbials, the time of reference will play an important role, but in order to cope with a larger set of facts and phenomena than the ones discussed in Reichenbach 1947 his notion of the time of reference has to be modified.

One such modification concerns the punctual nature of the time of reference. In Reichenbach 1947 R is invariably a single moment of time, but examples like (15) make it clear that the time of reference may be a period of some length as well. Partee is explicit on this: "From the fact that there are conditions requiring reference times to include events and to be included within states, i.e. within some period for which a given state holds, it follows that reference times must be construed as protracted events or bounded intervals." [Partee 1984, 255] This has some important consequences for the expressive power of the representation formalism (cf. section 4).

Another modification concerns the role of the time of reference in the representation of individual clauses. Reichenbach treats it as an intermediary between the time of event and the time of speech, but taking into account some developments in DRT, I will rather treat it as an intermediary between the time of event and a contextually determined point of perspective. The motivation for this modification is given in the next section.

2. The point of perspective

In Kamp and Rohrer 1983 the point of perspective is introduced for differentiating between various kinds of indexical and anaphoric time adverbials, and in Kamp and Rohrer ms. it is used for describing the meaning of the plus-que-parfait in flashbacks. As a first introduction, though, the need for a point of perspective, as distinct from both the time of speech and the time of reference, can most easily be demonstrated in the treatment of indirect discourse. In

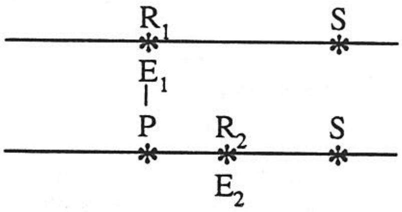
(21) John said: "I will come at 5"

the time of speech of the second clause is the time of John's utterance, which is in the past of the time of speech of the first clause. Shifting to indirect discourse we get

(22) John said that he would come at 5

in which there is only one time of speech. John's utterance is in the past of that time of speech, and provides a starting point for the interpretation of the subclause. The subclause has a time of reference, specified by "at 5", which is equal to its time of event, "John's coming", but not to the time of saying (E_1). As a matter of fact, its time of reference is in the future with respect to the time of saying:

(23)



In the terminology of DRT, the time of saying (E_1) provides the point of perspective (P) for the interpretation of the subclause.

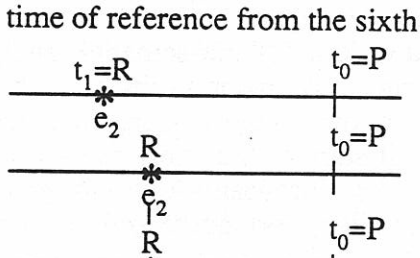
Notice that the transition from direct to indirect speech triggers a transposition of deictic into anaphoric expressions: this does not only affect the pronoun (I $\rightarrow$ he) but also the tense (will $\rightarrow$ would).

Given the distinction between point of perspective and time of reference one can express the difference between anaphoric and indexical time adverbials. An example of the former is "deux jours après" in the second clause of

(24) Kissinger arriva au Caire le sixième juillet.
Deux jours après il partit pour Jérusalem.
Il était très fatigué.

It shifts the time of reference from the sixth of July to the eighth:

(25)



Since the state in the third clause is located with respect to the current time of reference, it is interpreted to hold at the time of leaving for Jerusalem, i.e. July 8th.

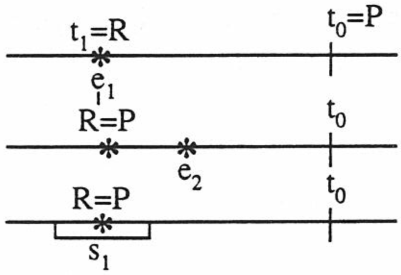
When "deux jours après" is replaced by the indexical time adverbial, "dans deux jours", we get another picture.

(26) Kissinger arriva au Caire le sixième juillet.
Dans deux jours il partait/*partit pour Jérusalem.
Il était très fatigué.

The leaving for Jerusalem takes place two days after July the 6th, as in (24), but in contrast to the anaphoric adverbial, the indexical adverbial does not shift the time of reference. Instead, it triggers a shift of the time of perspective into the past and describes the future leaving from that point of view.

It follows that the state in the third clause is interpreted with respect to July the 6th, and not with respect to July the 8th. Kamp and Rohrer 1983 analyses (26) as follows:

(27)



The point of perspective is dissociated from the point of speech and identified with the time of reference which is provided by the time of event of the first clause. This shift in the past triggers transposition and the imparfait in the second and third clause is therefore interpreted as if it were a présent simple (cf. the simultaneity of time of reference and point of perspective). This also explains why the passé simple is ungrammatical in (26): it is the imparfait and not the passé simple which results from a transposition of the présent simple.

In section 5 I will propose an alternative analysis of (26), but the intuition that one should distinguish between the time of speech and the point of perspective is one which I will adopt.

3. A parametric analysis of the forms of tense and aspect

One of the main functions of the discourse representation format to be developed in this paper is to serve as a framework for the semantic analysis of the grammaticalised forms of tense and aspect. A major problem with terms like "tense" and "aspect", though, is that no two authors seem to agree on what they actually mean. For that reason I will start with a short overview of the relevant forms in the nine languages of the European Community, i.e. Danish, Dutch, English, German, Greek, French, Italian, Portuguese and Spanish.

As demonstrated in Van Eynde 1991, they can be analysed in terms of five binary distinctions: [±past], [±future], [±perfect], [±imperfective], and [±progressive] [4]. The following table gives a survey of the distinctions which are relevant for each of the nine languages; the last column mentions the number of relevant distinctions:

	±past	±imperf	±fut	±perf	±progr	
Spanish	+	+	+	+	+	5
Portuguese	+	+	+	+	+	5
Italian	+	+	+	+	+	5
French	+	+	+	+	-	4
Greek	+	+	+	+	-	4
English	+	-	+	+	+	4
German	+	-	+	+	-	3
Danish	+	-	+	+	-	3
Dutch	+	-	+	+	-	3

Since each of the attributes can take two values, the maximum number of combinations for each language is 2^n, where n is the number of distinctions. For German, Dutch and Danish it is $2^3 = 8$:

past	fut	perf		past	fut	perf	
-	-	-	spricht	-	-	+	gesprochen hat
+	-	-	sprach	+	-	+	gesprochen hatte
-	+	-	sprechen wird	-	+	+	gesprochen haben wird
+	+	-	sprechen würde	+	+	+	gesprochen haben würde

In this case the maximum number of combinations equals the actual number of combinations. This is not the case for all languages, though. French, for instance, has four relevant distinctions, and hence $2^4=16$ possible combinations, but its number of actual combinations is 10 [5]:

past	fut	imp	perf		past	fut	imp	perf	
-	-	0	-	parle	-	-	0	+	a parlé
+	-	-	-	parla	+	-	-	+	eut parlé
+	-	+	-	parlait	+	-	+	+	avait aprlé
-	+	0	-	parlera	-	+	0	+	aura parlé
+	+	0	-	parlerait	+	+	0	+	aurait parlé

The reduction is due to the partial neutralisation of the [±imp] distinction.

For a similar analysis of the other Euro-languages, see Van Eynde 1991.

In the next sections I will use the term "tense forms" for the combinations of [±past] and [±future], and the term "aspect forms" for the combinations of [±imperfective], [±perfect] and [±progressive].

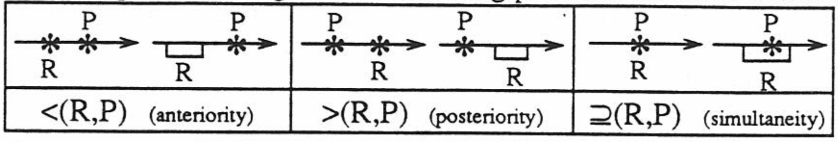
4. The compositional core

The determination of temporal relations in a text results from the interaction between the compositionally derived interpretations of the individual clauses, on the one hand, and the dynamically applied principles of discourse organisation, on the other hand. In this section I will concentrate on the compositional core of the format. The dynamic part will be discussed in section 5.

In keeping with the conclusions reached in sections 1 and 2 I will assume that the interpretation of each clause i in a text involves three temporal entities: a point of perspective P_i, a time of reference R_i and the interval for which the tenseless proposition holds, E_i. The point of perspective may be equal to the time of speech, but this is not necessarily so.

Following a proposal in Johnson 1981 I will make a distinction between a treatment of tense (4.1) and a treatment of aspect (4.2).

4.1. Tense concerns the location of R and its relation to P; since R cannot only be a point but also a period, one gets the following possible relations with P:



These correspond to the traditional notions of past, future and present; the reason for using terms like "anteriority" instead of the more familiar "past" is that the latter is already used for the tense form and that I do not want to suggest that the relation between tense forms and tense meanings is one-to-one.

There is just one small but significant departure from tradition: simultaneity is not defined as simple identity, but as inclusion. It follows that the time of reference in a clause with a simultaneous interpretation can cover the whole of the time line, and -conversely- that the only way to cover the whole of the time line is by means of a clause with a simultaneous interpretation. This goes a long way in explaining why it is the present that is used in so-called eternal truths and timeless clauses.

The three tense meanings are expressed by means of tense forms and indexical time adverbials:

anteriority: [+past,-future], yesterday, five days ago
posteriority: [-past,±future], tomorrow, dans deux heures
simultaneity: [-past,-future], maintenant

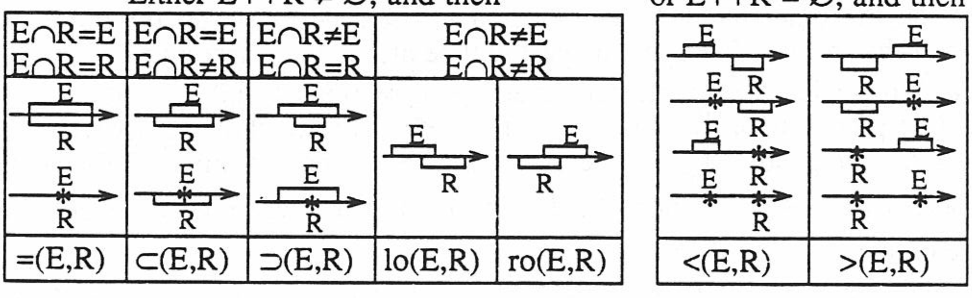
In order to find out which meanings a tense form can express one can apply a grammaticality test: if the tense can be combined with an indexical adverbial of type X in one and the same clause and after the effects of transposition have been undone, then the tense can express X. This yields the following results for the French forms of tense:

FR [-past,-future] → {simultaneity, posteriority}
[+past,-future] → {anteriority}
[-past,+future] → {posteriority}

The "conditionnel", [+past,+future], does not have a temporal meaning of its own; it acquires the meaning of the future in transposed contexts, but out of such contexts it expresses a modal meaning rather than a temporal one.

4.2. Aspect concerns the relation of E to R; since both E and R can be periods of a certain length, the number of their possible relations is higher than between R and P. The exact number can be determined in a deductive way:

Either $E \cap R \neq \varnothing$, and then or $E \cap R = \varnothing$, and then



It follows that there are seven possible binary relations between E and R [6].
These relations provide rather straightforward formalisations of such well-known aspectual concepts as

- **perfectivity:** the event is seen as a single unanalysable whole from the point of view of the reference time; *subpart-of*: =(E,R) or ⊂(E,R)
- **durativity:** the event is described as going on from the point of view of R; *proper inclusion*: ⊃(E,R)
- **retrospectivity:** the event is described as completed at R; this is the meaning usually associated with the perfect; *precedence*: <(E,R)
- **terminativity:** the event is described as leading up to the time of reference; there is a link here with the "current relevance" meaning of the perfect; *left overlap*: lo(E,R)
- **ingressivity/inchoativity:** the event is described as starting at the time of reference; *right overlap*: ro(E,R)
- **prospectivity:** the event is described as taking place in the future of the reference time; the futur proche is often taken to express this meaning; *succession*: >(E,R)

The six aspect meanings are expressed by the aspect forms and aspectual modifiers, such as duration and time span adverbials. Given the aim and the limited size of this paper I cannot go into the details of the relation between aspect forms and aspect meanings (cf. Van Eynde 1991 for discussion). For the purpose of illustration I only mention the correspondences for the aspect forms in French: FR

[-perf,-imperf]	→	{perfective}
[-perf,+imperf]	→	{durative,terminative}
[-perf,0imperf]	→	{perfective,durative,terminative}
[+perf]	→	{retrospective,terminative}

Prospectivity and inchoativity are expressed by the futur proche.
Taken together the treatments of tense and aspect cover the grammaticalised forms with a temporal meaning in a compositional way; for instance, the meaning of the imparfait is the result of combining the meaning of the past tense [+past,-future] with the meaning of the imperfective aspect [+imperf,-perfect][7].

5. The dynamic fringe

The compositional core concerns the temporal relations within individual clauses; for the specification of temporal relations across clause boundaries one needs principles for relating the times of perspective, reference and event of adjacent clauses.
The default case is that the time of perspective equals the time of speech and that both the time of perspective and the time of reference are kept constant: $P_1=S$, $P_i=P_{i-1}$ and $R_i=R_{i-1}$, for i>1. Things are not always that simple, though, and for the more complex cases we need rules for identifying the location of P_i, R_i and E_i. In this paper I will not spell out those rules in any detail; I only want to sketch a general format and notation for their formulation. The format has three modules, corresponding to the determination of P_i (5.1), R_i (5.2) and E_i (5.3).

5.1. The time of perspective can be shifted in the future or the past of the speech time, esp. in complement clauses; in that case the point of perspective is usually provided by the time of event of the dominating clause, as in

(22) John said that he would come at 5

TEMPORAL PERSPECTIVE	TENSE	ASPECT
$P_1=S$	$R_1<P_1$	$E_1 \subseteq R_1$
$P_2=E_1$	$R_2>P_2$	$E_2 \subseteq R_2$
	$R_2=\text{at } 5$	

Since E_1 precedes S, P_2 also precedes S, and this triggers transposition of "will" to "would" in the subclause. The tense and aspect meanings are determined by the regular rules for interpreting the simple past and the simple future where the latter results from undoing the transposition in the subclause.

Shifts of the time of perspective are not always marked by verbs of saying, as in (22); they are just as often left implicit and difficult to notice [8].

5.2. The time of reference can shift as well; it is the forward movement of the reference time which gets most attention in the literature (cf. Kamp, Rohrer, Dowty, Partee, Hinrichs), and for most authors there seem to be just two possibilities: either there is a forward movement, or there is no movement at all. I think that one should at least foresee the possibility of backward movement as well.

The most explicit way to signal the movement of the reference time is by means of anaphoric time adverbials, such as "two days later" and "five weeks before". They determine the location of the time of reference of the clause in which they appear with respect to the time of reference of some preceding or dominating clause. There are at least three possibilities:

identity:	at that moment, then
precedence:	five weeks before, two minutes earlier
succession:	two days later, deux jours après

Another way of signalling the movement is by means of the grammaticalised forms of tense and aspect. Indeed, following the observations made in DRT, one can make a distinction between the forms which can not trigger any movement, such as the imparfait, and those which can, such as the passé simple.

As applied to

(24) Kissinger arriva au Caire le sixième juillet.
Deux jours après il partit pour Jérusalem.
Il était très fatigué.

we get the following result

TEMPORAL PERSPECTIVE	TENSE	TEMPORAL ANAPHORA	ASPECT
$P_1=S$	$R_1<P_1$	—	$E_1 \subseteq R_1$
	$R_1=\text{July } 6$		
$P_2=P_1$	$R_2<P_2$	$R_2>R_1$	$E_2 \subseteq R_2$
		$R_2-R_1=2 \text{ days}$	
$P_3=P_2$	$R_3<P_3$	$R_3=R_2$	$E_3 \supset R_3$

The time of perspective is equal to the time of speech and does not move. The tense and aspect meanings are straightforwardly derived from the corresponding forms: $<(R,P)$ & $\subseteq(E,R)$ for the passé simple and $<(R,P)$ & $\supset(E,R)$ for the imparfait. The time of reference is first identified as July 6th and then shifted to July 8th by the anaphoric adverbial, "deux jours après". In the third clause there is no shift: $R_3=R_2$ [9]. The information that E_3 includes R_3, and therefore also R_2 and E_2, derives from the aspectual meaning of the imparfait: $E_3 \supset R_3$.

It is interesting to compare this analysis with the one of

(26) Kissinger arriva au Caire le sixième juillet.
Dans deux jours il partait/*partit pour Jérusalem.
Il était très fatigué.

TEMPORAL PERSPECTIVE	TENSE	TEMPORAL ANAPHORA	ASPECT
$P_1=S$	$R_1<P_1$ R_1=July 6	—	$E_1 \subseteq R_1$
$P_2=E_1$	$R_2>P_2$ $R_2-P_2=2$ days	—	$E_2 \subseteq R_2$
$P_3=E_1$	$R_3 \supseteq P_3$	—	$E_3 \subseteq R_3$

In this case there is no anaphoric information: the anaphoric adverbial is replaced by an indexical one, and the imparfait is not an anaphoric tense here (cf. $R_i=R_{i-1}$), but rather a transposed present. As a consequence it does not have its normal anterior meaning, but rather the meaning(s) which the présent simple has, i.e. a posterior meaning as in the second clause or a simultaneous meaning as in the third clause.

5.3. As far as I can see, natural languages do not provide any explicit means for relating the event times of adjacent clauses; it is, however, possible to compute these relations on the basis of the relations between the respective reference and perspective times. For (24) this computation would go as follows:

TEMPORAL PERSPECTIVE	TENSE	TEMPORAL ANAPHORA	ASPECT	TEMPORAL INFERENCING
$P_1=S$	$R_1<P_1$ R_1=July 6	—	$E_1 \subseteq R_1$	$E_1<S$
$P_2=P_1$	$R_2<P_2$	$R_2>R_1$ $R_2-R_1=2$ days	$E_2 \subseteq R_2$	$E_2>E_1$
$P_3=P_2$	$R_3<P_3$	$R_3=R_2$	$E_3 \supset R_3$	$E_3 \supset E_2$

Clause 1: if $E_1 \subseteq R_1$ and $R_1<P_1$, then $E_1<P_1$, and if $E_1<P_1$ and $P_1=S$, then $E_1<S$.
Clause 2: if $E_2 \subseteq R_2$ and $R_2>R_1$, then $E_2>R_1$, and if $E_2>R_1$ and $E_1 \subseteq R_1$, then $E_2>E_1$.
Clause 3: if $E_3 \supset R_3$ and $R_3=R_2$, then $E_3 \supset R_2$, and if $E_3 \supset R_2$ and $E_2 \subseteq R_2$, then $E_3 \supset E_2$.

These results conform to the intuitions that the arrival in Cairo (E_1) is before the time of speech, that the departure for Jerusalem (E_2) follows E_1, and that the protagonist feels tired at a time (E_3) which includes the time of the departure.

In a comprehensive treatment the rules for inferencing should be explicitly defined and formalised. This I intend to do in future work.

6. A comparison with the current DRT-approach

The format for the representation of temporal expressions which was developed in the two previous sections is -in a number of ways- similar to the one proposed in Rohrer (1986) and Kamp & Rohrer (ms.). It therefore makes sense to compare them in some detail.

6.1. The DRT format looks as follows:

TEMPORAL PERSPECTIVE	TENSE	PROGRESSIVE	PERFECT
[±PAST]	{pr,pa,fu}	{+,-}	{+,-}

Temporal perspective has two values: +PAST and -PAST. The former indicates that the point of perspective precedes the time of speech (P_i<S); in that case the tenses are usually transposed.

The tense values are the semantic present, past and future.

"The feature PROGRESSIVE with the values + or - is intended to express aspectual information. A verb form which contains the feature +PROG denotes a state, a verb form with the feature -PROG denotes an event. Furthermore a verb form with -PROG "brings the action forward", or in more technical jargon, the denoted event lies after the reference point. Verb forms with +PROG don't 'bring the action forward'." [Rohrer 1986, 80]

"The feature PERFECT also has the two values + and -. It is used to capture the notion of a "perfectum praesens". We want it to denote a state which is the result of a preceding event." [ibid.]

The first two features -Temporal Perspective and Tense- are very much like their equivalents in my format; there are only some minor differences.

As for temporal perspective, its value in DRT only says whether or not the point of perspective precedes the point of speech; in my system it is explicitly identified with some specific time introduced before, and whether that time precedes S is a matter of inferencing. Since the [±PAST] information is probably all one needs to know for the treatment of the forms of tense and aspect, DRT's treatment may be justified on this account. However, if the objective is to make the temporal structure of a text explicit, one probably needs to be more specific about the location of P.

As for tense, the main difference is that I define simultaneity (semantic present) as inclusion, rather than as coincidence, thus offering an explanation for the use of the present in so-called eternal truths (cf. 4.1).

The more important differences between both treatments concern the features Progressive and Perfect.

The feature PROGRESSIVE concerns the "forward movement of time", like TEMPORAL ANAPHORA in my treatment, but there are three major differences. First, I distinguish more values than the two which DRT provides; apart from forward movement [-PROG] and lack of forward movement [+PROG] I also foresee the possibility of backward movement, thus providing a way for accomodating such anaphoric adverbials as "two days earlier" and "five weeks before". Second, the value of PROG depends to a large extent on the aspectual type of the clause (event vs. state), whereas the ANAPHOR value is determined only by the forms of tense and aspect and the anaphoric time adverbials. Third, whereas PROG concerns the relation between R and e_i or s_i (where R is provided by e_j for j<i), ANAPHOR concerns the relation between R_i and R_{i-1}. The determination of the relation between adjacent E's in my alternative is left to the INFERENCING module.

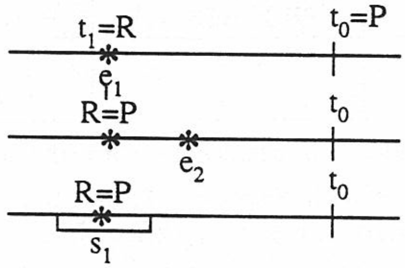
As for the feature PERFECT, it is subsumed under my treatment of ASPECT. The latter is more comprehensive than the former, since it also includes a treatment of the [±imperfective] and the [±progressive] distinctions. In contrast to DRT, I claim that these distinctions are not only relevant at the level of discourse (cf. their different values for PROG) but also at the level of the individual clause.

6.2. To illustrate the differences between both treatments I will compare their analysis of

(26) Kissinger arriva au Caire le sixième juillet.
Dans deux jours il partait/*partit pour Jérusalem.
Il était très fatigué.

The DRT treatment has already been given in section 2:

(27)



In terms of the four features it can be summed up as follows:

TEMPORAL PERSPECTIVE	TENSE	PROGRESSIVE	PERFECT
[−PAST]	past	-	-
[+PAST]	pres	-	-
[+PAST]	pres	+	-

In terms of my treatment it would be represented thus:

TEMPORAL PERSPECTIVE	TENSE	TEMP. ANAPH.	ASPECT	TEMPORAL INFERENCING
$P_1=S$	$R_1<P_1$ R_1=July 6	—	$E_1 \subseteq R_1$	$E_1<S$
$P_2=E_1$	$R_2>P_2$ R_2-P_2= 2 days	—	$E_2 \subseteq R_2$	$E_2>E_1$
$P_3=P_2$	$R_3 \supseteq P_3$	—	$E_3 \subseteq R_3$	$E_3<E_2$

The main differences concern the second clause, more specifically the location of R. In (27) it is provided by e_1 and equal to P; the fact that e_2 follows e_1 is due to the relation between e_2 and R. In my treatment R includes E_2, and the fact that E_2 follows E_1 is attributed to the relation between R and P. It follows that I have to stipulate two meanings for the present (simultaneity and posteriority), but there is plenty of independent motivation for that: many linguists and logicians, including Kamp and Rohrer, have postulated a posterior meaning for the present, next to its simultaneous one (cf. 4.1).

The difference between the two treatments may seem insubstantial, at this point: both $P=R<e_2$ and $P<R_2$ E_2 predict that $P<E_2$, and since $P=E_1$, that $E_1<E_2$.

Let us now take a slightly more complex example, though:

(29) Kissinger arriva au Caire le 6 juillet.
Dans deux jours il aurait visité 5 pays.

Applying the rules for the representation of the passé simple and the conditionnel II, DRT would derive the following values:

TEMPORAL PERSPECTIVE	TENSE	PROGRESSIVE	PERFECT
[–PAST]	past	-	-
[+PAST]	fut	+	+

The TENSE value specifies that the state (s_2) resulting from the preceding event of visiting 5 countries is in the future with respect to P, and the PROGRESSIVE value predicts that there is no forward movement, hence that s_2 does not follow R, but rather includes it (it is explicitly said in Rohrer 1986 that [+Perf] tenses are [+Prog]). Notice, however, that there is a problem here. Indeed, if s_2 is in the future of P and includes R, then it follows that R has to follow P, but if R is determined by e_1, as normal DRT practice dictates, then it has to be equal to P. One could, of course, claim that normal DRT practice in this case is overruled and that R has to be put in the future of P (and e_1), but this would amount to a rather cavalier treatment of the indexical adverbial: in (26) it would specify the distance between R and e_2, and in (29) it would specify the distance between P and R.

In my treatment, on the other hand, the indexical adverbial can consistently be interpreted as specifying the distance between P_i and R_i:

TEMPORAL PERSPECTIVE	TENSE	TEMP. ANAPH.	ASPECT	TEMPORAL INFERENCING
P_1=S	R_1<P_1 R_1=July 6	—	$E_1 \subseteq R_1$	E_1<S
P_2=E_1	R_2>P_2 R_2-P_2= 2 days	—	E_2<R_2	E_2?E_1 [10]

The conditionnel II in (29) is a transposed future perfect, which gets its regular interpretation (R>P and E<R) and which can be unified in a straightforward way with the indexical time adverbial.

7. Conclusion

The resulting treatment has a number of attractive properties:

- it provides a format for the representation of temporal relations in texts, in terms of which the contributions of the individual temporal expressions can be described;
- the text representations are derived and interpreted in a compositional way; this holds both for the processing of texts (cf. the distinction between a compositional core and a dynamic fringe) and for the analysis of the grammaticalised forms of tense and aspect (cf. the distinction between a treatment of tense and a treatment of aspect);
- it provides a conceptual framework for the comparison of the tense and aspect systems of different languages.

Notes

1. "Event" is used here as a cover term for state, process and event. Throughout the paper I will follow the convention that E or E_i stands for the interval at which a tenseless proposition holds, regardless of whether this proposition is a state, a process or an event. If the distinction matters, I will use lower case letters, such as e for event, and s for state.
2. Pragmatic considerations lead one to assume that E_5 precedes E_4, since the introduction will presumably have occurred before the writing of the letter, and that E_4 precedes E_2, since the writing will no doubt have occurred before the start of the journey; this information, though, is not so much based on linguistic knowledge (the meaning of the pluperfect) as on common sense entailment.
3. Since this principle does not mention tense, it will not only be applied when the second clause is in the passé simple, but also when it is in the imparfait. In that case there is a problem, since the analysis might well predict that E_2 follows, rather than includes E_1. Indeed, if

   R_1<S $\quad E_1$=R_1 (passé simple)

   $\quad R_2$>R_1 (forward movement)

   R_2<S $\quad E_2 \supset R_2$ (imparfait)

   then it is not impossible that E_2>E_1. For that reason Dowty requires that R_i immediately follow R_{i-1}.
4. A more comprehensive survey should also include the futur proche (aller+infin, to be going to+infin) and -perhaps- its past counterpart (venir de+infin). See also note 5.

5. Taking into account the futur proche would lead to the addition of two more forms: the présent "va parler" and the imparfait "allait parler". Similarly, one could add two forms for the "immediate past": "vient de parler" and "venait de parler".
6. Allen 1984 distinguishes no less than 13 binary relations between intervals. They result from differentiating between various types of sub-intervals (initial, final, middle) and precedence (immediate vs. non-immediate). Since these further distinctions are not grammaticalised in the Euro-languages I will not adopt them here.
7. There are a few exceptions to this scheme; the present perfect in German, Dutch and French, for instance, does not only express retrospective simultaneity, as predicted by the rules for the present and the perfect, but also perfective anteriority, which is one of the regular meanings of the simple past.
8. Rohrer 1986 discusses several examples in which the point of perspective is not provided by the saying event but by some other time of reference or event in the preceding text. There will, no doubt, be some constraints on the choice of an anchor for the point of perspective, but I prefer to leave the investigation of this topic for further research.
9. In Vet and Molendijk 1986 it is argued that $R_i = R_{i-1}$ is a constant feature of the French imparfait.
10. The relation between E_2 and E_1 cannot be determined unequivocally on the basis of the tense and aspect forms; pragmatic knowledge tells us that E_2 properly includes E_1, but this is a matter of common sense entailment, rather than of inferencing from linguistic information.

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Disambiguation in Discourse

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0. Introduction.

This note is one in a series. The series consists of case studies concerned with the role that lexical information and lexically driven inference play in the construction of semantic representations of discourses. We hope that such studies will eventually lead to a clear perspective of the inferential mechanisms that are needed in text and discourse interpretation and of the kind of information which these mechanisms exploit as premises. There is - of this we are convinced - no quick and easy way to get at such a comprehensive picture; only a long and thorny path, leading past a large number of particular examples painstakingly scrutinized, is likely to lead us to such a comprehensive view. Each analysis along this path ought to produce some new insights into the nature of natural language interpetation; but it would be foolish to expect any one of them to reveal the whole truth.

In this regard the present study is no exception. Like others we have carried out over the past two years, it yields some glimpses of the general principles that govern discourse interpretation. But a reasonably comprehensive understanding of those principles is, we fear, still a very long distance ahead.

The present study differs from our earlier case studies[1] in that the problems it considers have a direct bearing on (automated) translation. For the case we will consider concerns the role which context plays in the interpretation of a lexically ambiguous word (the German verb *ausleihen*, which can mean either *borrow* or *lend*). When a German text is translated into, say, English, each

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Most of what has gone into this paper arose out of joint work with Antje Roßdeutscher. Those familiar with that work will know the depth of my indebtedness.

[1]Kamp & Roßdeutscher (1992), Roßdeutscher (1992), Roßdeutscher (1993)

occurrence of *ausleihen* must be disambiguated, for otherwise one would not know which of the two English verbs to use. Note, however, that it isn't just when we translate into English that the ambiguity of *ausleihen* needs to be resolved. A German speaker will typically assign a particular reading to any occurrence of the verb he encounters, whether or not he knows English, let alone is engaged in English translation. So the same ought to be the case for any text-understanding system.

Nevertheless this paper holds a special moral for the business of translating by machine. It is a moral that comes in two parts. First, it should be evident from reading this note that an MT system able to deal with the problems we will discuss must have inferential capacities quite unlike anything that can be found in the systems which are in operation at the present time. If one keeps in mind that those problems are still quite trivial when compared with those that cause genuine trouble to professional translators, it is not easy to preserve even moderate optimism about the MT enterprise. At the very least they support a sense of sobriety.

That a certain sobriety is called for becomes especially clear when one realizes - and here we come to the second moral- that translation systems which can deal with the kind of problem we will discuss must be able to disambiguate not just in those (arguably infrequent) cases where disambiguation is directly needed for the choice of a suitable target language equivalent. Disambiguations like the one we will look at depend crucially on the availability of an explicit and unambiguous representation of the discourse or text which *precedes* the ambiguous item in question. This means that whenever the translation system encounters an expression whose disambiguation is needed for translation purposes, it must either have such a representation of the antecedent discourse, or else it will have to construct it then and there. In order to secure that the representation is there when required, the system will have to build it as it goes along, much as a question answering system would do with a text about which it must be able to answer subsequent queries. A system that forgoes building such representations in the hope that they won't be needed, may be lucky in that no complicated context-dependent inferences will be wanted throughout the text with which it is dealing; but if it is not lucky, it will have to start all over or go back a considerable way; and so it might have been better off had it taken the more arduous course of building a proper discourse representation from the outset. There is no hope in either case that a powerful MT system can be significantly simpler than a fully-fledged discourse interpreter.

1.

We will concentrate on the following pair of examples:

(1) A: Du hast das Buch doch, oder?
B: Ich habe es gekauft. Aber ich habe es ausgeliehen.

(2) A: Du hast das Buch doch, oder?
B: Ich habe es nicht gekauft. Aber ich habe es ausgeliehen.

(1) and (2) can be translated as

(1.e) A: You've got the book, don't you?
B: I bought it. But I have lent it to somebody.

(2.e) A: You've got the book, don't you?
B: I didn't buy it. But I have borrowed it.

In (1) *ausleihen* translates as *lend*, in (2) as *borrow*.

We begin with an informal explanation of the difference between (1) and (2):

The two different uses of the verb *ausleihen* - one corresponding to *lend* and one corresponding to *borrow* - both involve change of possession. But the changes are in opposite directions: while the lender gets rid of the object, the borrower gets hold of it. The *lend*-use of *ausleihen* describes transitions from a state in which the subject is in possession of the object to one in which he isn't, and the *borrow*-use describes transitions from the latter state to the former. *Kaufen* too describes changes of this general type - changes from a state in which the subject does not have an object to one in which he does have it. So the result of the event described in the first sentence of (1) is a state in which the subject has the book. This situation is fit as a starting point for an event of the type described by the second sentence if *ausleihen* is understood as *lend*, but not when the verb is interpreted as *borrow*. This means that if we take *ausleihen* in this second sense, then we must assume that between the two events mentioned - the buying event and the borrowing event - there was a third event, which changed the state of the subject having the book into that of his not having it. When *ausleihen* is taken in the sense of *lend*, no corresponding assumption is necessary. So (simplifying considerably) the first interpretation yields the less complicated interpretation and therefore qualifies as the correct one.

With respect to (2) the argument is similar, but not altogether. We just saw that verbs like *ausleihen* and *kaufen* express transitions from states of one type into states of the opposite type. However, the status of these two facts - of the initial presence of a state of the first type and the eventual holding of one of the second type - is different. The latter is part of what the verb is used to assert, whereas the former rather has the character of a presupposition: it tends to be seen as holding not only when the verb is used affirmatively, but also when it occurs in a denial. In particular, the first sentence of (2) is naturally understood as pertaining to a period at the outset of which the subject did not have the book.[2] Moreover, it claims of this period that it contains no event of the described type (i.e. no event of B buying that book). This time, therefore, it is the *lend* interpretation which leads to difficulties. Since at the beginning of the period that the first sentence is taken to be about the subject did not have the book, and since for all the first sentence has to tell us this state of affairs was not terminated, the precondition for the *lend* interpretation of the second sentence is not fulfilled - if it were fulfilled, this would have been in virtue of some event which the discourse does not mention. The *borrow* interpretation does not run into this problem here. Its precondition is fulfilled by the state of affairs presupposed by the first sentence; there is no need to assume the occurrence of some unmentioned event.

Summarizing, the intuitively preferred interpretation of *ausleihen* is in either case that which avoids assuming the occurrence of events that are not entailed by the antecedent text; the better interpretation is that which can make do with a minimum of happenings.

Put this way the principle of disambiguation in (1) and (2) is reminiscent of a number of theories about non-monotonic temporal reasoning which define non-monotonic consequence relations as preservation of truth by those and only those models of the premises in which the set of events and/or states of affairs is in

[2] As is the rule with presuppositions, this species of presupposition is easily cancelled. It is, for instance, in:

(3) Ich habe das Buch nicht gekauft. Ich besitze es schon seit Jahren.

some sense minimal.[3] This parallel, however, could be misleading in two ways. First, as noted explicitly in Lorenz (1993), there is an important difference between on the one hand the non-monotonic inferences relevant in the contexts for which most of those theories appear to have been designed - contexts of predicting a state of affairs that is still to come or of explaining an observed state on the basis of incomplete information - and on the other the non-monotonic inferences that often arise in discourse interpretation and that are exemplified by the reasoning apparently involved in making sense of (1) and (2). The justification for assuming minimality when explaining or predicting facts about the world is that *this* world - the one in which we live - tends on the whole to be fairly regular; events of the sorts that we are most ready to identify as causes of states or other events are the exception rather than the rule. They may be likely occurrences in situations of some particular kind, but are unlikely to occur otherwise. Thus the default inferences we tend to make in explanation and prediction and which involve the assumption that certain events did or will not occur are supported by the way the world is, by the statistical distribution of events of one type over situations of some other type; it has nothing to do with the ways we speak about what we know.

The justification of non-monotonic inferences like the ones we encountered in our gloss of examples (1) and (2) is of a different kind. In these examples the speaker in question, B, may be assumed to know what happened. If indeed he bought the book, then got rid of it or had it taken from him, and then proceeded to borrow it, this would have been a sequence of events he himself would have known about. And if he did know about it, then, in order to avoid possible misunderstanding, he could, and should have mentioned it. That he should have mentioned it is a convention of speech, one of the rules governing cooperative verbal communication. Given this convention, the very fact that B's utterance does not mention that he came to be without the book after he had bought it may be taken as evidence that no such event occurred: Had the intention been that such an event occurred, then the event would have been explicitly mentioned. Because of this communicative convention, minimalization inferences in discourse interpretation tend to be very reliable. Such a convention is applicable especially to fiction, where the author can be assumed to know all there is to know about the world of his narration. Here inference by minimalization is usually a sound means of arriving at

[3]See for instance McCarthy(1986), Lifschitz(1986, 1987), Shoham (1988), Kautz (1986), Kowalski and Sergot (1986), Sandewall (1988), Schubert (1990), Lorenz (1993).

the intended interpretation (i.e. for arriving at a representation of the described world that matches the author's intentions).

There is a second respect in which the parallel between the cases at hand and the minimalization approaches towards non-monotonic reasoning in the AI literature is less than perfect. As we will see in section 2, examples (1) and (2) are a good deal more complex than the informal analyses we have just given reveal. Thus, in connection with (1) we have so far ignored the possibility that the *ausleihen*-event described by the second sentence of B's answer does not follow the *kaufen*-event of the first, but that the two events stand in some other temporal relation. For instance, could they not have been simultaneous, or even identical? Another aspect we have ignored is the role played by the word *aber* , which figures in both (1) and (2). When we will eventually turn to these issues, we will find that event minimalization is anything but the whole story there is to tell about these tiny dialogues.

2. Representing B's first Answer.

But first we must put the given analyses on a firmer formal footing. We start with (1) and proceed as follows. We almost entirely ignore A's question, since, on the account we will be formalizing, it is not directly relevant to the interpretation of B's second sentence. The only information implied by it which we need to retain is that there is among the individuals shared between A and B some particular book (viz. the book to which A's question refers; for a first pass at an analysis of shared information witin a DR-theoretical framework see Kamp (1990)). I will assume that this book is represented by the discourse referent b and will state the condition which guarantees that b does indeed stand for the book in question somewhat ineptly as *das Buch (b).* Thus we start with a DRS consisting merely of the following:

(3)

b
the book (b)

We now sketch the construction of a representation for the first sentence of B's answer. After that we will show how the two different interpretations of *ausleihen* lead to two distinct extensions of this representation and how the "good" extension is simpler than the other one. Then, having completed our account of (1), we will go through the same exercise for example (2).

Semantic representations are constructed as in DRT: Discourse representations (DRSs) are built sentence by sentence, with each new sentence yielding an extension of the DRS for the preceding text. By and large we assume that the construction procedure is as developed in Kamp & Reyle (1993), but there is one important difference. For present purposes it is crucial that DRS construction involves the use of a lexicon, which specifies the relevant syntactic and semantic properties of the words that make up the processed sentences. A sketch of how the construction procedure would exploit lexical entries for certain verbs can be found in Kamp & Roßdeutscher (1992). This proposal is also the basis for the procedure followed here.

To work out a lexically based construction procedure in full detail is a major undertaking, with which we have so far only made a start. To become fully explicit, such a procedure would need to have a lexicon at its disposal that contains entries for all words that it encounters in the texts with which it is to deal. A lexicon of such size, but whose entries contain the kind of information that is exemplified in the few entries we will give below, is still a thing of the future. So we will have to be content as in Kamp & Roßdeutscher (1992) to make the construction-lexicon interaction explicit only in the case of the two words on which the present disambiguation strategy depends - the verbs *kaufen* and *ausleihen* - and to deal with all other words in the manner of earlier construction algorithms (such as the one in Kamp & Reyle(1993). That is, the expressions besides *kaufen* and *ausleihen* will be treated as 1-place predicate, 2-place predicate, predicate modifier, etc.

To see how a DRS construction procedure can exploit the lexical entry for a verb, it is best to first have a look at an example. Here is the entry we propose for the verb *kaufen*:

$$
\begin{array}{lllll}
 & \textit{kaufen} & \text{Nom} & \text{Acc} & \textit{von} + \text{Dat} \\
(4) & e & x & y & (\ z\ )
\end{array}
$$

$$
e: \quad \begin{array}{|ll|}
\hline
 & e_c \quad e_e \\
 & \\
 & e_c \ \text{Caus}_{\textit{kaufen}} \ e_e \\
 & \\
 & \text{Agent}(e_c) = x \\
 & \\
e_e: & \text{TRANSFER}(y, z, x) \\
\hline
\end{array}
$$

Like other verb entries (4) consists of an upper an a lower part. The upper part, consisting of the top two lines of (4), specifies the *syntax-semantics-interface*. To be precise, it stipulates how the semantic arguments (e, x, y, z), which figure in the lower, purely semantic part of the entry, are syntactically realized when the verb is used in its "basic" (i.e. active) form. That is, when the verb is used in an active clause, its "non-referential" arguments (x, y and, perhaps, z) are realized by phrases with the "case markings" indicated in the top line - as subject, direct object and as prepositional phrase with *von*, respectively. The parentheses around z indicate that this argument is syntactically optional (an active clause with *kaufen* as main verb need not contain the PP, whereas every such clause must have a subject and a direct object). Besides the arguments x, y and z, *kaufen* also has a "referential argument" e. e is the event which the given use of the verb describes. The lower part of the entry says that each such event is a "causal complex" consisting of an action e_c (the c stands for "cause") by the agent x which stands in a special causal relation $\text{Caus}_{\textit{kaufen}}$ to the process e_e (the e stands for "effect". For details see Kamp & Roßdeutscher (1992)). This process is the transfer of the purchased item from the seller, z, to the buyer, x.

There are various other properties which buying events necessarily have and which one might expect the lexical entry for *kaufen* to make explicit, e.g. that such events require a certain kind of action on the part of the seller as well as on the part of the buyer or that buying always involves a transfer in the opposite direction of a certain sum of money. As these aspects of the meaning of *kaufen* play no role in the arguments below, we have chosen not to include them in (3); however, a comprehensive entry for *kaufen* ought to include them.[4] The binary predicate $\text{Caus}_{\textit{kaufen}}$, the 1-place

---

[4]Entries like (3) make no attempt to distinguish between the two levels which in the work of Bierwisch and others (see e.g. Bierwisch (1983), (1988), (1989), Wunderlich (1992)) is called *semantic form* and *conceptual structure*.

function Agent and the 4-place predicate TRANSFER are elements of a "concept language" in which the purely semantic part of the lexicon is formulated. The logical properties of and the relations between these concepts are made explicit in another component of the lexicon, to which we will refer as the *(set of) meaning postulates* or *lexical axioms*. One of these postulates says that a transfer of y from z to x leads from a state in which y is had by z and not by x to a state in which it is had by x and not by y:

(5)			
	e y z x		s_p s_r
			s_p)(e)(s_r
		$\Rightarrow$	s_p: HAVE(z, y)
	e: TRANSFER(y, z, x)		s_p: $\neg$ HAVE(x, y)
			s_r: $\neg$ HAVE(z, y)
			s_r: HAVE(x, y)

We assume that the verb *ausleihen* has two lexical entries, one for each of the uses we distinguished. They look much like the entry for *kaufen*:

The idea behind this distinction is that lexical items have a variety of semantic properties, in particular those that have to do with the syntactic realizations of their arguments, which can be read off a certain comparatively uninformative level of semantic representation - that of semantic form - which will in general not suffice for the full indentification of the truth conditions associated with sentences in which those lexical items occur. A lexical entry containing a semantic form which answers these desiderata would need no separate syntax-semantics-interface, since the information for which that interface is responsible could be gleaned from the semantic form in any case. On the other hand, the entry would have to either contain a separate conceptual structure or else the additional information needed to compute conceptual structure from logical form. Precisely how this juxtaposition or transition between semantic form and conceptual structure is to be conceived and represented appears to be still a topic of investigation.
So long as this issue has not been clarified it is difficult to assess the exact relationship between the verb entries proposed here and in the other papers cited in fn 1 and those proposed in the studies cited in the present footnote.

$$
\begin{array}{lllll}
 & \textit{ausleihen}_1 & \text{Nom} & \text{Acc} & \textit{von} + \text{Dat} \\
(6) & e & x & y & (\ z\ )
\end{array}
$$

$$
e: \boxed{\begin{array}{ll}
 & e_c \qquad e_e \\
 & e_c \ \mathrm{Caus}_{borrow} \ e_e \\
 & \mathrm{Agent}(e_c) = x \\
e_e: & \mathrm{TRANSFER}(y, z, x)
\end{array}}
$$

$$
\begin{array}{lllll}
 & \textit{ausleihen}_2 & \text{Nom} & \text{Acc} & \textit{an} + \text{Acc} \\
(7) & e & z & y & (\ x\ )
\end{array}
$$

$$
e: \boxed{\begin{array}{ll}
 & e_c \qquad e_e \\
 & e_c \ \mathrm{Caus}_{lend} \ e_e \\
 & \mathrm{Agent}(e_c) = z \\
e_e: & \mathrm{TRANSFER}(y, z, x)
\end{array}}
$$

Note that the only points at which the entry for *ausleihen*$_2$ differs from that for *ausleihen*$_1$ are (i) the causal relations Caus$_{borrow}$ and Caus$_{lend}$ and (ii) the syntax-semantics interface; this time it is z which is realized as subject, while x has become optional and when it is realized at all, it is not as subject but as a PP with *an*.

To make use of the entry for *kaufen* in constructing a representation of the first sentence of B's answer in (1) the construction algorithm must be able to identify, via a preliminary parse it has built for the sentence, the set of argument phrases which qualify, in virtue of their configurational relations to the given occurrence of *kaufen*, as potential arguments of it. This set has to be checked against the syntax-semantics interface of *kaufen*'s entry (4) to see if all the arguments which the entry specifies as obligatory are in the set (with the right case markings and/or prepositions) and further whether some of the syntactically optional arguments are present as well. If the match is successful, the variables marking the argument positions in the lexical entry are identified with the discourse referents introduced by the corresponding argument phrases and the structure that results from making these identifications in the purely semantic part of the entry is introduced at the place held by the verb in the DRS. In the present case the only identifications are between x and the discourse referent i introduced for the first person pronoun *ich* (see Kamp (1990)) and between y and the discourse referent u for the pronoun *es*, which in turn is identified with the discourse referent b for the pronoun's anaphoric antecendent. For further details see Kamp & Roßdeutscher (1992).

Combining this procedure with construction principles familiar from earlier accounts of DRS construction, we arrive at

(8)

$n \quad e_1 \quad e_{1c} \quad e_{1e} \quad b \quad i \quad u \quad z_1$

das Buch (b) $\quad i =$ the speaker; $\quad u = b$

$e_1 < n$

e_1:

$\quad e_{1c}$ Caus$_{kaufen}$ e_{1e}

$\quad$ Agent(e_{1c}) $= i$

$\quad e_{1e}$: TRANSFER(u, z_1, i)

Axiom (5) permits us to expand (8) to (9):

(9)

$n \quad e_1 \quad e_{1c} \quad e_{1e} \quad i \quad b \quad u \quad z_1 \quad s_{1p} \quad s_{1r}$

$i =$ the speaker; $\quad$ das Buch (b) $\quad u = b$

$e_1 < n \qquad s_{1p}$)(e_{1e})(s_{1r}

e_1:

$\quad e_{1c}$ Caus$_{kaufen}$ e_{1e}

$\quad$ Agent(e_{1c}) $= i$

$\quad e_{1e}$: TRANSFER(u, z_1, i)

s_{1p}: HAVE(z_1, u)
s_{1p}: $\neg$ HAVE(i, u)
s_{1r}: $\neg$ HAVE(z_1, u)
s_{1r}: HAVE(i,u)

We must now process the second sentence of (1) in relation to (9). As we noted, the result will depend on which lexical entry for *ausleihen* the construction algorithm is going to select. (Note that argument matching does not decide the matter, since the complements of the present token of *ausleihen* include neither a *von-* nor an *an*-PP.) We present the two outcomes as (10) (corresponding to $\textit{ausleihen}_1$) and (11) (corresponding to $\textit{ausleihen}_2$)

(10) $n \quad e_1 \quad e_{1c} \quad e_{1e} \quad i \quad b \quad u \quad z_1 \quad s_{1p} \quad s_{1r}$

i = the speaker   das Buch (b) $u = b$

$e_1 < n \qquad s_{1p}\ )(\ e_{1e}\ )(\ s_{1r}$

e_1: $\boxed{\begin{array}{ll} & e_{1c}\ \mathrm{Caus}_{kaufen}\ e_{1e} \\ & \mathrm{Agent}(e_{1c}) = i \\ e_{1e}: & \mathrm{TRANSFER}(u, z_1, i) \end{array}}$

s_{1p}: $\mathrm{HAVE}(z_1, u)$
s_{1p}: $\neg\ \mathrm{HAVE}(i, u)$
s_{1r}: $\neg\ \mathrm{HAVE}(z_1, u)$
s_{1r}: $\mathrm{HAVE}(i, u)$

$e_2 \quad u \quad e_{2c} \quad e_{2e} \quad s_{2p} \quad s_{2r} \quad z_2$

$e_2 < n \qquad s_{2p}\ )(\ e_{2e}\ )(\ s_{2r}$

e_2: e_{2c} Caus_{borrow} e_{2e}

$\mathrm{Agent}(e_{2c}) = i$

e_{2e}: $\mathrm{TRANSFER}(u, z_2, i)$

s_{2p}: $\mathrm{HAVE}(z_2, u)$
s_{2p}: $\neg\ \mathrm{HAVE}(i, u)$
s_{2r}: $\neg\ \mathrm{HAVE}(z_2, u)$
s_{2r}: $\mathrm{HAVE}(i, u)$

(11) n e1 e1c e1e i b u z1 s1p s1r

i = the speaker das Buch (b) u = b

$e1 < n$ $s1p$)($e1e$)($s1r$

e1: e1c $Caus_{kaufen}$ e1e

Agent(e1) = i

e1e: TRANSFER(u, z1, i)

s1p: HAVE(z1, u)

s1p: ¬ HAVE(i, u)

s1r: ¬HAVE(z1, u)

s1r: HAVE(i, u)

---

e2 u e2c e2e s2p s2r z2

$e2 < n$; $s2p$)($e2e$)($s2r$

e2: e2c $Caus_{lend}$ e2e

Agent(e2) = i

e2e: TRANSFER(u,i,z2)

s2p: ¬ HAVE(z2, u)

s2p: HAVE(i, u)

s2r: HAVE(z2, u)

s2r: ¬ HAVE(i, u)

To evaluate and compare (10) and (11) we need to make an additional assumption about the temporal relation between $e1_e$ and $e2_e$. In our informal analysis we assumed that $e1_e < e2_e$. For the time being we simply adopt this assumption. We will turn to the question of its justification in Section 4.

First consider (9). Simple temporal reasoning allows us to infer from the premisses

(i) $e1_e < e2_e$
(ii) $e1_e \;)(\; s1_r$
(iii) $s2_p \;)(\; e2_e$

the conclusion

(iv) $(s1_r < s2_p) \vee (s1_r \circ s2_p)$

Together with the following two conditions from (10):

(v) $s1_r$: HAVE(i, u)
(vi) $s2_p$: $\neg$ HAVE(i, u)

we can infer, first, that the second disjunct of (iv) is impossible: since the two states satisfy contradictory predicates, they cannot overlap. Consequently only the first disjunct remains:

(vii) $s1_r < s2_p$

But in order that a state of one type (here;$\neg$ HAVE(i, u)) can follow one of the opposite type (here: HAVE(i, u)) there must have been an intervening event which effected the change. There are various ways in which this principle can be formulated. Here is one:

(12)

$s1 \quad s2 \quad x_1, \ldots, x_n$
$s1 < s2$ $s1$: $P(x_1, \ldots, x_n)$ $s2$: $\neg P(x_1, \ldots, x_n)$

$\Rightarrow$

e
$s1 \;)(\; e < s2$

Using (10) we can infer that there must have been such an event between $s1_r$ and $s2_p$. So, restricting ourselves to the relevant part of the "temporal structure" of (10), we get

(viii)

$n \quad e1 \quad e1_c \quad e1 \quad s1_p \quad s1_r \quad e2_e \quad s2_p \quad s2_r \quad e3$
$e1_e \;)(\; s1_r \;)(\; e3 < s2_p \;)(\; e2_e < n$

As noted above, this structure is problematic from the perspective of text coherence, as the event $e3$, which must have occurred between $s1_r$ and $s2_p$, is not mentioned in (1). Moreover, as we will see presently, no such extra assumption is forced upon us by (11).

To see this, note that corresponding to the condition (vi) of (10) we have in (11) the condition

(ix) $s2p$: HAVE(i, u)

Thus the characterizing predicates of $s1r$ and $s2p$ coincide. Consequently it is possible to assume that $s1r$ and $s2p$ are (parts of) one and the same state, so that the corresponding temporal structure implied by (11) has the form:

(x)

n	e1e	s1p	s1r	e2e	s2p	s2r
	e1e)(s1r)(e2e < n					
	s1r = s2p					

Thus (11) does not force us to assume the existence of events that are not mentioned in the text, and thus its temporal structure is simpler than that of (10). So, in accordance with the minimalization principle it should be (11), not (10) that represents the correct interpretation of (1).

We already stressed that the role of minimalization in discourse interpretation should not be conflated with the one it plays in causal explanation and prediction. Indeed, for future reference it will be useful to summarize what is involved in the present use of minimalization once more.

(i) The premisses of the argument contain the claim that

(a) the occurrence of ***ausleihen*** in the second sentence of (1) is either an instance of ***ausleihen1*** or of ***ausleihen2***.

This premiss combines with

(b) the DRS (8) for the first sentence of (1)
(c) the syntactic structure of the second sentence which functions as input to the construction of (10) and (11) and
(d) the (relevant) principles defining the construction algorithm

to yield the disjunction consisting of the DRSs (10) and (11). The models of this disjunctions are either models of (10) or models of (11). All models of (10) have at least the events and states represented by the discourse referents of (10) together with the discourse referent e3 occurring in (viii). Among the models of (11) there are also models in which the only represented events and states are those represented by the discourse referents of (11). These models are simpler than any of the models of (10). So all minimal models of the disjunction verify (11).

As we intimated before, there is a good deal more to say about (1) than the present analysis reveals. But before turning to those other issues, we first present a similar analysis for the seond answer of B.

3. B's Second Answer

After all that has been said about B's answer in (1), we will be able to deal with his answer in (2) fairly swiftly, for most of the relevant issues have already been discussed. But there are two points connected with (2) that are new. The first has to do with the representation of negations of past tense (and future tense) event sentences. Such sentences assert of some period of time that within it no event of the sort described by the unnegated sentence occurred. In some cases this period is indicated explicitly by a temporal adjunct, in others it has to be reconstructed from the context, or simply guessed at. The case at hand is one of the latter kind: By his use of the simple past tense B suggests that there was some interval of past time during which acquiring the book was an issue. It is of this interval that he asserts no purchase took place. In (13), a DRS for the first sentence of (2), the interval is represented as t:

(13)

$$\boxed{\begin{array}{l} n \quad t \quad i \quad b \quad u \\ i = \text{the speaker} \qquad \text{das Buch}(u) \qquad u = b \\ t < n \\ \neg \; \boxed{\begin{array}{l} e_1 \quad e_{1c} \quad e_{1e} \quad z_1 \\ e_1 \subseteq t \\ e_1: \boxed{\begin{array}{l} e_{1c} \;\; \text{Caus}_{kaufen} \;\; e_{1e} \\ \text{Agent}(e_{1c}) = i \\ e_{1e}: \; \text{TRANSFER}(u, z_1, i) \end{array}} \end{array}} \end{array}}$$

The second point concerns the presuppositional aspect of the verb *kaufen*. Many telic verbs (i.e. verbs expressing actions with well-defined result states), *kaufen* and *ausleihen* (in both senses) among them, *presuppose their prestates*. The occurrrence of an event that such a verb describes presupposes that there be a certain state of affairs when it starts, a state of affairs that is opposite to the result state type associated with the verb - this must be so, for otherwise there would be no way for the event to *bring about* its result state. The way in which we interpret negated clauses with telic verbs shows that the presence of the prestate is a matter of presupposition in the technical sense of the word: unless the assumption is explicitly cancelled, the interpreter will assume that the prestate holds at the outset of the period t over which it is being claimed that no event of the indicated type occurred. Thus, the first sentence of B's answer in (2) implies that at the beginning of t B was in a state opposite to that which would have resulted from his buying the book, that is, in the state of his not having the book. In (14) - which is in all other respects just like (13), the presupposition about the prestate has been explicitly incorporated[5]:

[5] The rule responsible for the introduction of the state s in (14) can be stated as follows. As we saw in (5), a telic verb like *kaufen* induces a postulate to the effect that each instantiating event is flanked by a state of the associated result type at the one end and a corresponding, opposite prestate at the other. When such a verb occurs in a negated clause, which gives rise to a sub-DRS K governed by $\neg$, which denies the existence of an event of the given type over a certain period t, then information must be added to the DRS which contains K as sub-DRS to the effect that the prestate held at the beginning of t. This information takes the from of adding a new discourse referent for the state, a condition which says that the represented state is of the type of a prestate for the given verb and a condition expressing overlap with the beginning of t.

Described in this way the rule seems rather ad hoc. However, the need for it will disappear in a DRS-construction account which would incorporate a component dealing with presupposition in general. Such a theory would have to provide principles to handle presuppositions whose triggers occur within the scope of negation, to make sure that these presupposition are incorporated into the representation unless cancelled explicitly. Given such principles, all that would be needed to insure the transition from (13) to (14) is a specification that the presence of a prestate is, unlike the subsequent occurrence of a result state, something which the verb presupposes.

(14)

$n \quad t \quad i \quad b \quad u \quad s$

i = the speaker das Buch (b) $u = b$

$t < n$ $s \; O \; beg(t)$[6]

$\neg$
  $e_1 \quad e_{1c} \quad e_{1e} \quad z_1$

  $e_1 \subseteq t$

  e_1:
    $e_{1c} \; \mathrm{Caus}_{kaufen} \; e_{1e}$

    $\mathrm{Agent}(e_{1c}) = i$

    e_{1e}: $\mathrm{TRANSFER}(u, z_1, i)$

s: $\neg \; \mathrm{HAVE}(i, u)$

For how long does the prestate associated with a telic verb persist? This is a separate question, with answers that depend on how the verb is being used. When the verb occurs in a positive clause, which asserts the occurrence of an event of the given type, then this event will terminate the prestate, by turning it into the result state. If the clause is negative, as it is in the present case, then the state will be assumed to persist, though the extend of this persistence needs to be determined by some other mechanism. This principle of (conditional) persistence enters into the ambiguity resolution in (2) just as the persistence of the result state of *kaufen* did in our analysis of (1).

To complete the present analysis of (2) is now straightforward. Once more we extend the representation of the first sentence - that is (14) - twice, once on the assumption that *ausleihen* is used in the sense of *borrow* and once on the assumption that it is used in the sense of *lend*. The resulting representations are given in (15) and

---

[6]The relation between s and t which is expressed here is that where s must have been in existence when t began - s and t overlap, but s "sticks out beyond t" in the direction of the past. The relation can be straightforwardly defined in Allen's sytem of temporal relations, but we won't bother.

(16). This time it is the *borrow*-sense of *ausleihen* which leads to the simpler DRS, and thus qualifies as the preferred interpretation.

(15) n t i b u s

i = the speaker das Buch (b) u = b

t < n s O beg(t)

$\neg$

e_1 e_{1c} e_{1e} z_1

$e_1 \subseteq t$

e_1: e_{1c} Caus_{kaufen} e_{1e}

Agent(e_{1c}) = i

e_{1e}: TRANSFER(u, z_1, i)

s: $\neg$ HAVE(i, u)

- -

e_2 u e_{2c} e_{2e} s_{2p} s_{2r} z_2

e_2 < n s_{2p})(e_{2e})(s_{2r}

e_2: e_{2c} Caus_{borrow} e_{2e}

Agent(e_{2c}) = i

e_{2e}: TRANSFER(u, z_2, i)

s_{2p}: HAVE(z_2, u)
s_{2p}: $\neg$ HAVE(i, u)
s_{2r}: $\neg$ HAVE(z_2, u)
s_{2r}: HAVE(i, u)

(16) $n \quad t \quad i \quad b \quad u \quad s$

i = the speaker   das Buch (b) $u = b$

$t < n$ $s \ \bigcirc \ \mathrm{beg}(t)$

$\neg$ [$e_1 \quad e_{1c} \quad e_{1e} \quad z_1$

$e_1 \subseteq t$

e_1: [e_{1c} Caus_{kaufen} e_{1e}

$\mathrm{Agent}(e_{1c}) = i$

e_{1e}: $\mathrm{TRANSFER}(u, z_1, i)$]]

s: $\neg\ \mathrm{HAVE}(i, u)$

$e_2 \quad u \quad e_{2c} \quad e_{2e} \quad s_{2p} \quad s_{2r} \quad z_2$

$e_2 < n \quad s_{2p} \ )(\ e_{2e} \ )(\ s_{2r}$

e_2: [e_{2c} Caus_{lend} e_{2e}

$\mathrm{Agent}(e_2) = i$

e_{2e}: $\mathrm{TRANSFER}(u, i, z_2)$]

s_{2p}: $\neg\mathrm{HAVE}(z_2, u)$
s_{2p}: $\mathrm{HAVE}(i, u)$
s_{2r}: $\mathrm{HAVE}(z_2, u)$
s_{2r}: $\neg\ \mathrm{HAVE}(i, u)$

4. Things are not as simple as they seem.

Things are not as simple as they may have seemed so far. That they aren't has a couple of reasons.

The first reason has to do with the temporal relation between the *kaufen*-event e_1 and the *ausleihen*-event e_2 in (1). In our treatment of (1) we assumed without argument that the second event occurred after the first. But what is the justification for this assumption?

It has often been noted that there is a natural tendency for speakers to report events in the order in which they actually happened. In particular, when a text contains a sequence of past tense event sentences S_1, S_2,... the assumption that the event e_1 described by the first sentence preceded the event e_2 described by the second, etc. is often a good bet. But it is not much more than that. Exceptions to the principle abound and one would have to be remarkably obtuse not to see them. Indeed, the early literature on tense and aspect within DRT, which adopted the principle as a first approximation for past tense narrative, acknowledged the existence of such exceptions, although it didn't offer any formal proposals for how they could be recognized and assigned the correct interpretations.[7] The last few years have seen substantial progress on this point, mostly through the work of Lascarides and Asher and others, which exploits the systematic connections between on the one hand the temporal relations between states and events and on the other the rhetorical relations between the sentences which describe them.[8] This work has done much to sharpen our perception of the complexity of the problem, but precisely because the problem is so very complex, we have at this point still no more than fragments of a full theory. Moreover, the applicability of what theory there is to the examples of this paper is especially problematic, since the theory has so far concentrated on the interpretation of monologue. Even within single-speaker texts the principles governing temporal and rhetorical interpretation appear to be varying substantially with genre - whether the text is a narrative, a joke, a scientific or argumentative piece of prose, a servicing or operating manual, etc.. When we turn to dialogue, the

[7]See for instance Kamp (1981), Kamp & Rohrer (1983), Partee (1984), Hinrichs (1984)

[8]See for instance Lascarides & Asher (1991), and the already cited Asher (1993). Also relevant are Caenepeel (1989), Caenepeel & Sandström (1993), Sandström (1993).

matter is even more different than that; and dialogue has, from the perspective that is here relevant, barely been looked at.

In view of this an analysis of our examples that takes rhetorical as well as temporal relations into account would require substantial groundwork, which would reach far beyond the limits of the modest aims of this paper. So we leave this task for another occasion.

As it turns out, in the present case all new possibilities that arise when the assumption is dropped can be eliminated by the kinds of considerations that we used in the preceding sections. Suppose for instance that in (1) e_1 and e_2 were simultaneous. There are two cases to be considered: e_1 and e_2 might be one and the same event, or they might be distinct but overlapping events. First consider the case of their being identical. If *ausleihen* is interpreted as *borrow*, we would have a single event that would at the same time be a buying and a borrowing of the book. Clearly that cannot be, for buying and borrowing are incompatible kinds of actions.

But the second possibility, that where e_1 and e_2 are distinct but overlapping events, is ruled out also. Once you are engaged in buying a given object, you cannot then also borrow it. For - we have made similar points repeatedly before - you would first have to get rid of the thing again; only then could you proceed to borrow it from its new owner. By the same token, once you have set about borrowing the thing, you cannot then at the same time go about buying it.[9]

The situation is no better when we interpret *ausleihen* as *lend*. First, lending something and buying it cannot be the same event. Moreover, as we have seen repeatedly, to lend an object you have to have it and to buy it you have to not have it. So the events of buying an object and lending it out cannot overlap.

So we can rule out the possibility that e_1 and e_2 are wholly or partly simultaneous. What about e_2 being before e_1? The assumpton that an event of B's borrowing the book preceded the event of his buying it runs into the same difficulties we already encountered: there should have been an intermediate event to change the result state of the borrowing back into one where B did not have the book. This speaks against reading *ausleihen* as *borrow*.

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[9] But see below!

Now suppose that *ausleihen* is interpreted as *lend*. Here the type of incompatibility argument we used in the last paragraph to eliminate the *borrow*-interpretation won't work. As we represented $ausleihen_2$ and *kaufen* in Section 2, the result state of $ausleihen_2$ would seem to be precisely the precondition required by *kaufen*. So by the argumentation we have been using so far the present interpretation ought to be all right. But intuitively it isn't, and the question is why? We suspect that this is a fact that can be explained in more than one way. The explanation we offer here has to do with the contractual aspects of *buy* and *lend*. When you buy a thing, you not only have the use of it; you have actually become its owner. This is not so when you borrow something. You may use what you have borrowed, but ownership remains with the one who has lent it to you. Turning things around, if you first buy a thing, you become its owner and so are in a condition that allows you to do all manner of things with it. For instance, you can sell the thing again, or you can lend it to someone. But if you first lend something out, this does not create a condition in which it is possible for you to buy the thing. You still own it and buying presupposes that you do not.[10]

We repeat emphatically: this is not a definitive analysis. Nonetheless it should have given an impression of how far it is sometimes possible to go with the comparatively simple analytical tools we have been using. It would be in line with the way we have been proceeding so far to check what these tools yield in the case of (2), but this is something we will leave as an exercise. In stead we will devote the remaining pages to a point which so far has been entirely ignored, but which changes the look of things considerably when it is taken into account.

The point is this. We have been assuming all along that there was one object b, the book in question, which could be bought or borrowed, but not both. There are many contexts in which such an assumption is warranted. Consider e.g. the following English example, which closely parallels (1).

(17) A: Did you finally get that house on Lakeshore Drive you liked so much?

B: We did buy it. But we rented it.

---

[10] Note that the impossibility of buying what you have just lent derives from the contractual properties· properties of these verbs. This inforamtion is missing from the entries for *kaufen* and $ausleihen_2$ which we gave in Section 2. Complete entries for these verbs shouild of course contain this information.

(18) A: Did you finally get that house on Lakeshore Drive you liked so much?

B: We didn't buy it. But we rented it.

(17) and (18) present the same disambiguation problem as (1) and (2). But there is one important difference between the English examples and the ones we have been considering so far. (17) and (18) can only be understood as concerning one unique physical object, the house on Lakeshore Drive. If B bought that house then he cannot at the same time have rented it from someone. But not so with books. When A asks whether B has a certain book, he may be asking about some particular copy, e.g. the one that he, A, had previously lent to B. But B's replies in (1) and (2) suggest that that wasn't the context in which the question was asked. From what B is saying in response to A, it may reasonably be inferred that "the book" in A's question was a type - a text, of which there are presumably many copies. And when "the book" is understood this way, the claim that you cannot at the same time buy and borrow it holds no water. You can buy one copy and borrow another. Nevertheless this possibility does not affect the way in which (1) and (2) are interpreted. In fact, all those whose judgement we have tested did get the interpretations we informally described in Section 2; and when queried, they all testified to having understood the book to be a book in the type, not the token, sense. In the light of what we have been saying this is puzzling: Why is it that we cannot get a reading for B's answer to the effect that he has now got the book twice over - one copy borrowed and one copy bought?

The solution to this problem crucially depends, it turns out, on the role of discourse particles. To see this compare the following possible answers to A's question:

(19) A: Du hast das Buch doch, oder?

B: (a) Ich habe es gekauft. Aber ich habe es auch ausgeliehen.

(b) Ich habe es gekauft. Ich habe es auch ausgeliehen

(c) Ich habe es gekauft. Und ich habe es auch ausgeliehen.

(d) Ich habe es gekauft. Und ich habe es ausgeliehen.

In cases (a) - (c) the clearly preferred intepretation is that B bought one copy and borrowed another, in other words, precisely the one that is not available for (1). (d) seems to allow for both interpretations.

The moral of the comparison between (1) and (19) is clear: A proper analysis of texts such as (1) and (2) presupposes a detailed theory of discourse particles such as *aber* and *auch*. In particular, the analysis should be able to explain the crucial difference between (1) and (19.a) - i.e. the difference between *aber* + *auch* and *aber* on its own. The analysis we have been able to offer falls well short of this (even if it almost succeeds in dealing with the problem presented by (17) and (18).

We conclude with a hint of how the discourse particles in (1) and (19) produce the effects we have observed. When the verb *ausleihen* is interpreted as *lend*, then the second sentence becomes closely parallel in semantic structure to the first: both describe ways of B's acquiring the book. It is a curious but important property of discourse that when such parallels are sufficiently transparent, then the second of the two parallel expressions must be explicitly marked for this parallel; one device for marking parallels is the German word *auch*, or, in English the words *also* and *too*.[11] But there are also other devices to mark such parallels. For instance, among the particles that can serve this purpose there are also *even* (German *sogar*) and emphatic *and* (or, in German, *und*). When these are present, there is no need for *also* or *too* no matter how palpable the parallel. *Und* is of particular interest in the present context;. its capacity for marking parallels explains why (d) is ambiguous: even without the support of an accompanying *auch*, *und* counts as a formal mark of the parallel which results when we take *ausleihen* to mean *borrow*, so here this interpretation is not ruled out. In contrast, when *und* is replaced by *aber*, as it is in our original example (1), *auch* must be present to render the parallel interpretation legitimate. For *aber* does not have this capacity.

But even if this points in the right direction, it is a long way from anything that could be called a systematic treatment. In a sequel to the present paper we will make an attempt to deal with some of the phenomena noted in this last section in a less impressionistic manner.

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[11]The insight into this aspect of the way in which many discourse particles function is due to Sæbœ . See in particlar Sæbœ (1990), (1993).

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How to preserve information in a dynamic environment: trees for temporal reasoning

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0. Introduction

Two questions are addressed in this paper:

1) How do we represent the information in English narratives about temporal dependencies between what is described?

2) How do such representations model our reasoning about temporal relations ?

When we distinguish temporal reference to events from their description, these questions require that we determine in what contexts the given temporal reference preserved, as fixed by a preceding part of the narrative, and in what contexts it changes. Aspectual information plays a core role in such reference shifts, as the DRT studies on temporal anaphora have shown (cf. Hinrichs 1986, 1988, Partee 1984, Kamp and Reyle 1992). In the representational tools used in this paper, Dynamic Aspect Trees (DATs), aspect controls the way these DATs develop during the interpretation process. A notion of a *chronoscope* is characterized to define reasoning as a certain set of licensed actions on a DAT, preserving the assumed truth of the information it contains obtained by processing the premises. Furthermore, the *perspective* indicates what the relation between describer and described event is. Perspectives shift and can be refined, though for the further details of these semantic operations the interested reader is referred to my forthcoming *Representing Time in Natural Language.*

1.Aspectual verbs as generalized quantifiers: the cube

English has lexicalized verbs that describe the onset, the middle or the ending of an event. These are included in the class of aspectual verbs. Though a plethora of syntactic studies of their properties exist, their semantic properties have been little studied. In an earlier paper (ter Meulen, 1990) I proposed to interpret these verbs as describing relations between the contextually given reference time t and event-type E : V_{asp} (t, E).[1] With this relational interpretation of aspectual verbs, the rich toolkit of generalized quantifier theory developed initially for NPs, becomes applicable.[2] Consider the following entailments with aspectual verbs:

1) a. Jane *has started* to read a chapter of a Batman story =>

Jane *has started* to read that Batman story

b. Jane *continued* to read a chapter of a Batman story =>

Jane *continued* to read that Batman story

c. Jane *has finished* reading a Batman story =>

Jane *has finished* reading a chapter of that Batman story

When the inference from part to whole is valid, as in (1a, b), the aspectual verb is monotone increasing in its right argument E , the event-type representing the (syntactic) complement. We call such verbs *right increasing*. The opposite inference from whole to part, as in (1c), is valid only for the *right decreasing* aspectual verbs. This classifies the verbs describing the onset and the middle of actions as right increasing (*start, begin,*

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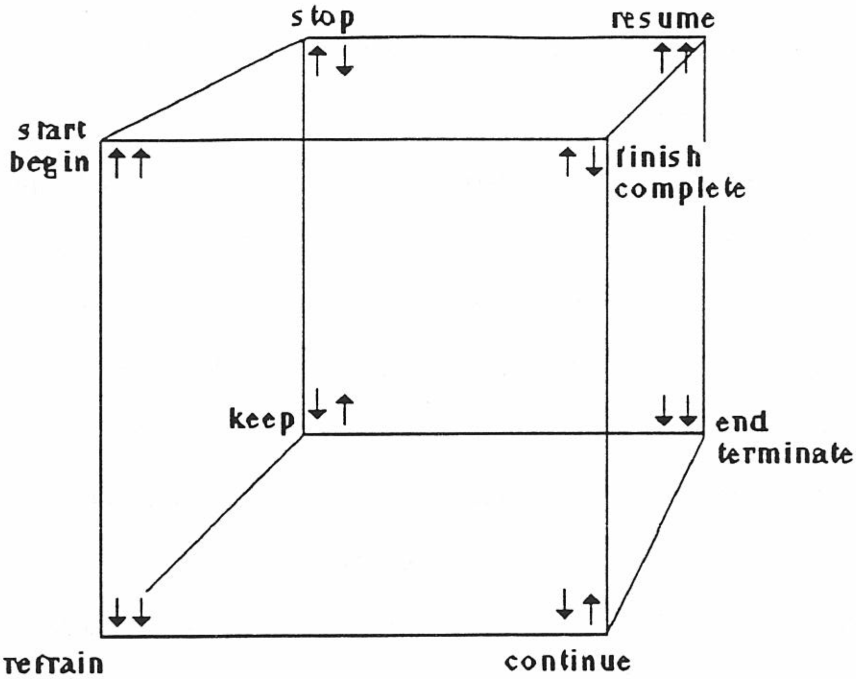
1 The contextually determined reference time is identified in DATs with the current node, ie. the node last constructed.

2 See Partee, ter Meulen and Wall (1990) for bacground on generalized quantifiers.

commence, initiate / keep, continue) and the verbs describing their ending as right decreasing (*finish, complete, terminate, halt*).

Note that (1a, c) are in the present perfect, whereas (1b) is in the simple past. This difference in tense marking is a manifestation of a crucial difference: those verbs that can be used in the valid part/whole inferences with the simple past describe universal, stative relations and preserve the given reference time, whereas the verbs that are valid only with perfect tense marking describe dynamic relations. i.e. change the given reference time as left argument to a later one. The existential aspectual verbs that need a perfect tense either have a positive polarity on the embedded event-type, describing the onset of an event (*start, initiate, begin*) or a negative one, turning it off as it were, describing its ending (*finish, end, terminate, complete, halt*). Such dynamic aspectual verbs denote the start or end, events that are atomic (in the given perspective) or 'disguise' their internal structure. These verbs are *left increasing* in shifting their left argument, whereas the universal ones, describing the ongoing or the continuation of an event, do not affect their left argument and are *left decreasing*, analoguous to the existential *(a, some, several*) and universal determiners (*all, every, each*) respectively. The left increasing verbs describe events that are called *plugs*, as they block further information from describing events that are temporally included in them. The left decreasing ones describe events called *holes* as they let further information flow through as descriptive of events temporally included in them and keep their left argument fixed.

These simple semantic properties lead to the following classification of aspectual verbs, visualized in a cube of oppositions. The horizontal lines represent a flip of the polarity on the event argument (internal negation) and the vertical lines the external negation on the polarity of the aspectual verb. E. g. to continue reading is not to finish reading, to resume reading is to stop not reading, to end reading is to continue not reading (assuming that you had been not reading before you started reading).



The cube of aspectual verbs

The cube projects the English aspectual verbs that take only gerundive complements on the back square, and the ones that take either gerundive or infinitival complements on the front. Each forms a full square of opposition patterns, with its four monotonicity combinations. Exceptions though, requiring a further explanation, are *finish* that takes gerundive complements only, and *cease* (not displayed, at same corner as *end*) that takes infinitival ones as well.

English apparently shows a lexical gap for the lower left front corner, where the complex externally negated *start* or, if we dive into intentional verbs, the non-aspectual verbs *refuse* or *refrain from* express the desired combination of monotonicity properties. It is an interesting issue for further research to see how this cube of aspectual verbs applies to other languages and gain more semantic insight into the universals of aspectual systems.[3]

[3] Dahl (1985) is a wonderful source of such semantic cross linguistic data on aspect.

Much more remains to be said about the relations between these aspectual verbs, especially their presuppositional relations. For instance, *keep*, that shares its monotonicity properties with *continue*, has a stronger presupposition, requiring that the action kept going is at the given time already going on, whereas *continue* allows its action to resume, if it is not actually going on. To resume reading a book presupposes that one has not only started reading that book, but has also stopped reading it, before starting it again where one had left off. Such presuppositions are not merely existential, requiring, for instance, that at some time in the past one had started to read this book, but they are *anaphoric*, requiring that this event being resumed has been started and stopped at an earlier time. The start, stop and resumption are part of one and the same event of reading this book, bound by the same anchoring of parameters or free variables.

The internal structure of events described by such aspectual verbs forms the basis of the representation of temporal anaphora in DATs discussed in thes next section. Every node in a DAT is internally structured as some transition through the cube, entering in *start* and exiting in either *end* to constitute a hole (an open node) or in *finish* to constitute a plug (a closed node).

2. *A story and its DAT representation* [4]

Much of what is usually studied about the semantics of single sentences concerns the statics of description. This is even true of the study of quantification and anaphoric binding across sentences in a text.[5] This paper does not address these matters at all, but is concerned with dynamics of the flow of information and perspective, and only in a minor way with the latter.

The information conveyed by text is decomposed into three kinds:

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[4] This section and the following are based on joint work with Dr. Jerry Seligman.

[5] The dynamic Montague semantics of Groenendijk &Stokhof is dynamic in the dynamic scoping of existential quantifiers, otherwise it is a truthconditional partial modeltheory.

1. **Statics**: what is asserted about the event currently referred to.

2. **Dynamics**: whether the next sentence is taken to describe the same event, or a different one; and, if the latter, which one.

3. **Perspective**: what is indicated about the relationship between the situation described and that of the describer.

The following linguistic features are relevant to the dynamics and perspective of description, with some illustrations occurring in the text below:

1. Aspectual class:	ACTivities,	*Batman patrolled the city*
	ACHievements,	*He started to laugh* [not in the story]
	ACComplishments,	*Catwoman dropped to the ground*
	STAtives,	*He knew he was close*

The principal semantic role of aspectual class is to provide information about the dynamics of description. Different dynamic functions are assigned to each of the above classes in constructing DATs.

2. Tense: The past tense and the present or past perfect require that the events they describe preceded the event of issuing the information. This is formalized as a constraint on the DAT construction, which is normally automatically satisfied in following DAT rules, once a first left branch is constructed as head of the anaphoric chain of temporal dependencies.

3. Aspectual Operators:	PROGressive,	*The punk was laughing hideously*
	PERFect,	*Fish-bones had been found in the pool*

Aspectual operators alter the dynamics of description. In a context in which a simple-past clause would indicate that a new event is referred to, either subsequent to or temporally included within the current one, the use of the past-progressive or past-perfect indicates that reference to the given event continues. In other words, aspectual operators change event-descriptions into state-descriptions.

4. Temporal Connectives:

Temporal connectives provide explicit information about the dynamics of description, which may overide information supplied by aspectual class. *Next* and *then* direct reference to a subsequent event, whereas *while* and *as* allow reference to simultaneous events.

To illustrate how a DAT is constructed by interpreting an English text, the following piece of fiction serves us as source.

> The streets of Gotham city were troubled by an unknown menace, once again. Its dark alleys were alive with nocturnal screams; dogs stayed inside and whimpered; and a large number of fish-bones had been found in the Mayor's swimming pool. High above those troubled streets, the sign of the bat flickered uncertainly, like the hopes of the good citizens who put it there.
>
> Below, the Dark Knight, feared by good citizens and unknown menaces alike, patrolled the dark night---and his even darker soul. Ignited with purpose, the Batmobile thundered along Central Avenue, then turned sharply into the narrow streets of the lower East side.
>
> Inside, Batman scowled. He knew he was close; but close to what? As the black car crawled past a deserted shopping centre, Batman watched four punks playing with a phone-booth. Glass shattered; the fattest punk was laughing hideously. "They don't count', thought Batman, scowling; and the Batmobile slid silently by.
>
> In a nearby alley,.a sleek, black form dropped to the ground on all fours. Razor-sharp nails extended from a leather mitten, and clawed the dirt. "Batman," she hissed, "At last!"

The content of a text is represented by a DAT: a labelled, ordered tree, with two sorts of nodes, and a distinguished "current" node. The DAT "grows" as the text is interpreted. The nodes stand for events referred to, and the arcs indicate temporal inclusion; the events represented by dependents of a node are temporal parts of the event represented by the dominating node. In addition, the left-to-right ordering of sister nodes represents temporal precedence of the events represented. There are two sorts of nodes: holes and plugs, represented diagrammatically by open circles and shaded circles respectively. The sort of the current node determines the way the DAT grows. There are two cases: if the current node is a hole, then the DAT grows a dependent node; whereas, if the current node is a plug, then the DAT grows a right sister of the current node. In either case, the new node becomes the current node.

These rules generate only right-branching trees, but there is a mechanism for returning to the higher levels: hole-filling. Given a signal from the text, the current node may jump to one of its ancestor-holes, turning it into a plug in the process. This is triggered when the text either explicitly describes the end of the event depicted by the ancestor-hole, or else describes an event which is incompatible with the continuation of the ancestor-event. From a logical point of view, this is the most difficult mechanism to account for, since it involves a certain degree of defeasibility.

The nodes of the trees are labelled by types of various sorts. Here we take types to be either atomic, or prefixed by an aspectual operator; but a fuller account (of the "statics" of description) would invest them with a much richer logical structure.

The two aspectual operators have the following functionality:

PERF: SITuation --> STAte

PROG: EVEnt --> STAte

For example, *Batman-patrolled-the-streets* is an ACTivity, and PROG[*Batman-patrolled-the-streets*] (= "Batman-was-patrolling-the-streets") is a state.

PERF(PROG[*Batman-patrolled-the-streets*]) (= "Batman-had-been-patrolling-the-streets") is also a state; and we cannot iterate the application of PROG. The statics of description consists in stating that the situation referred to is of the described type. This is modelled by the labelling of nodes by the names of types: each labelled node stands for the proposition that the situation represented by the node is of the type named by the label. The dynamics of description is modelled by the evolution of the DAT, as controlled by a text. For simplicity, we idealise a text as a sequence of types. Starting with the first type, a DAT is built up as we move through the sequence of types, according to the following rules:

let T be a type;

(i) if T is an ACT, grow a hole and label it with T;

(ii) if T is an ACH, grow a plug and label it with T;

(iii) if T is an ACC, grow either a hole or a plug and label it with T;

(iv) if T is a STA, label either the current-node or a right sister with T.

In addition, if T indicates the end of an ancestor-hole, fill it. Proviso: if T is incompatible with an ancestor-hole, fill it first.[6] In each case, it is the combination of the sort of the current node and the sort of the type that determines how the DAT evolves. The contribution of the current node has already been described: it determines where the DAT can grow a new node. The contribution of the sort of type is to determine what sort of node is grown, if any, and how it is labelled. It also signals when hole-filling can occur. The perspective of the text is given, at least in part, by its tense. In the above text, this is the past tense. The past is an activity that has just ended before issuing the information. The unlabelled root represents the event encapsulating both the entire episode described by the text as well as the event of issuing the information in the form of this text.

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[6] Exactly what is meant by "incompatible" will be addressed, albeit briefly and probably inadequately. For now, the reader is asked to appeal to informal intuitions.

Stative information does not make a DAT grow a new node, but its corresponding type is appended to the type labelling the current node. There are three forms of stative information:

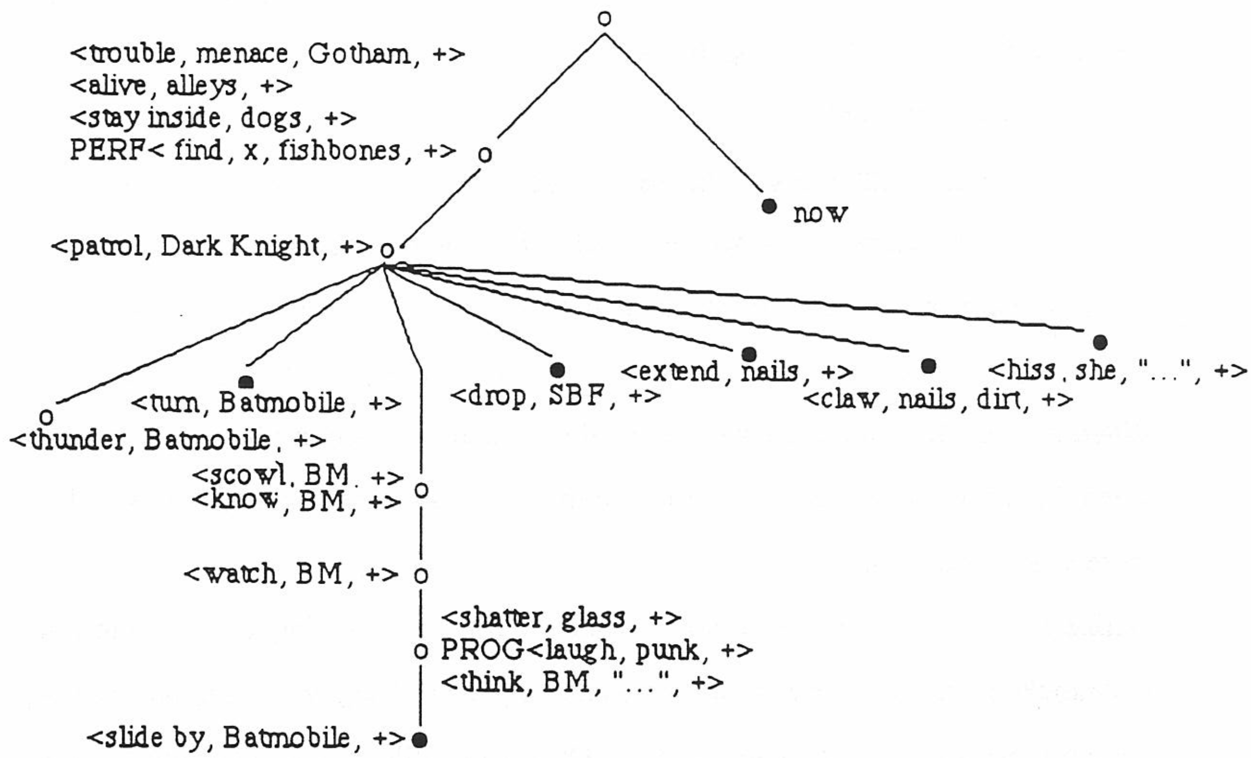
1) simple states	*Its dark alleys were alive with nocturnal screams*
2) perfect states	*A large number of fish-bones had been found in the Mayor's swimming pool.*
3) Generic states	*Dogs stayed inside and whimpered*

Such stative information is introduced locally on the current node, but its type can be transformed into a *portable* type by an operation similar to lambda-abstraction. For instance, from a parameterized type «***know***, *x*, + » a *portable* type is formed by placing the type in the restrictive term of the universal aspectual verb *KEEP* , abstracting over its free parameters ***KEEP*** [*x*, | «***know***, *x*, + »]. A situation supports such a portable type when it either does not support the restrictor, or, if it does, it also supports the new type labelling the node to which the portable type is transferred. This intended interpretation is based on the semantic properties of *KEEP*, shared with universal determiners or adverbs. Making the types representing stative information portable lets stative information percolate up the DAT when the perspective shifts and a new sister node is introduced. Stative information constitutes the bagage of constraints transported along in constructing a DAT for a text. The three kinds of stative information differ in their portability conditions: simple states are weakest in this respect, generic information is strongest and may percolate even to the root of the DAT. Perfect stative information encoded as ***HAVE*** [*x*, | «***R***, *x*, + »] is portable into new nodes, but must be dropped in perspective refinement, when the current node jumpes back to an earlier plug preceding the node at which the stative information was introduced.[7] There are more difficult problems to

[7] At the workshop I learned about a 'Monotonicity constraint' in the paper by Caenepeel & Sandström It seems to me their constraint amounts in DATs to requiring perspectival refinement to jump back only to terminal plug nodes to introduce their internal structure.

consider of information loss in perspectival refinement or in counterfactual reasoning that are unfortunately beyond the scope of the present paper.

These rules and principles produce the following DAT for the Batman story. The types labelling the nodes have been reduced somewhat for expository simplicity and contain no parameters, nor coreference conditions for pronouns.



3. Reasoning with DATs

DATs are designed to make temporal anaphora arising from the interpretation immediately visible. Reasoning with such information can now be modelled as an action on such DATs. Let's consider the following simple examples of situated inferences, where the sentences above the line are given information (Premises) and the ones below the conclusions (* stands for an invalid inference).

2) a. Batman watched

Glass shattered

Batman watched

Batman watched,

*after/ while the glass shattered

b. A sleek black form dropped to the ground

Razor-sharp nails extended from a leather mitten

A sleek black form *dropped/had dropped ...

Nails extended ... after/*while ...form dropped...

c. Batman watched four punks...

Glass shattered

The fattest punk was laughing hideously

The fattest punk laughed while/*after Batman watched

Batman saw the fattest punk laugh

When is a simple past tense conclusion valid? We already see in (2a) vs. (2b) that even when the information was given in the simple past tense, the conclusion in simple past tense is not always valid.

Define a *chronoscope* as a set of nodes in a DAT forming a continuous path from a given node to the root, together with the types labelling them. The *current chronoscope* is the chronoscope containing the current node. One of the following two conditions must be satisfied for a simple past tense conclusion to be valid:

1) the node with the label encoding the information expressed in the conclusion, is in the current chronoscope

2) the current chronoscope has a non-empty intersection with a chronoscope containing the node with the label encoding the information expressed in the conclusion with the appropriate temporal connectors (*while, before, after*)

Perfect tense conclusions license the current node to move up within the current chronoscope to the lowest node in its intersection with a chronoscope containing the causing event. It opens up the interpretors choice of continuing within either one chronoscope, but such more complex forms of indeterminacy were not needed for our Batman story, and would lead beyond the intended limits of this paper.

Appendix: DATs as formal objects:

Types are formed according to the following formation rules, recursively specifying the class of types *TYPE*.

(i) T is a *basic* type in *TYPE* iff. T is a sequence consisting of an n-ary relation R, n objects $a_1,\ldots, a_n$, and a positive or negative polarity + or -.

(ii) T is a *parameterized* type in *TYPE* iff. T is a basic type in which the relation or at least one object is replaced by a parameter R or a_i. respectively.

(iii) if T is in *TYPE* and x is an object parameter then x_T is a restricted object parameter. If T contains x_T , T is a *restricted parametrized type* in *TYPE*.

(iv) if T and T' are in *TYPE*, then so is the *conjoined type* «T & T' » and the *conditional type* «$T \Rightarrow T'$ ».

(v) Nothing else is in *TYPE* unless it is obtained by the clauses in (i) - (iv).

There is a fundamental notion of *compatibility* of types. Any two types are compatible iff. there is a situation that supports both in the same chronoscope. Obviously, any type is compatible with itself, and incompatible with its negative counterpart with a negative polarity or any of its entailments. Knowledge of the world will supply a host of basic (in)compatibility relations between types, encoded as constraints in the lexicon. Two sets of types are compatible iff. their union is compatible; and a single type T is compatible with a set S of types just in case $S \cup \{T\}$ is compatible.

A DAT consists of :

(i) a finite set of nodes, $N = \{n, n', \ldots, n_m\}$

(ii) a function δ_N from N to N^*, where N^* is the set of non-repeating finite sequences of N, assigning to each node n a sequence of nodes, its immediate dependents $\delta_N(n)$.

(iii) a function π_N from N to N, assigning to a node n the immediately dominating node as its parent $\pi_N(n)$. (So $\pi_N(n)$ is definable from $\delta_N(n)$.)

(iv) a subset H_N of N, the *H*oles; $N - H_N$ is the set P_N of plugs.

(v) a function α_N from N to the powerset of *TYPE*, assigning each node a set of types.

(vi) a distinguished node c_N in N, the current node.

such that

1. $\forall n, n'$ in N, n is in $\delta_N(n')$ iff. $\pi_N(n) = n'$

2. There is one and only one node, the root, that is its own ancestor (n is an ancestor of n' iff.$\exists n_1, ..., n_m$ ($m \geq 2$) such that $n_i = \pi_N(n_{i+1})$, $n = n_1$ and $n' = n_m$).

3. The set of all types labelling the ancestors of a node n (i.e. $\cup\{\alpha_N(n') | n'$ is an ancestor of $n\}$) is compatible with those types labelling n itself.

Information accumulation is modelled by a growing DAT. It is defined as an ordering on DATs as follows: $D_1 < D_2 = D_1 \cup \{c_{D2}\}$ and either

1. (Hole rule) c_{D1} is in H_{D1} and each of δ_{D2}, π_{D2}, H_{D2} and α_{D2} extends the corresponding function of D_1 with the single exception that $\delta_{D2}(c_{D1}) = < c_{D2} >$, or

2. (Plug rule) c_{D1} is in P_{D1} and each of δ_{D2}, π_{D2}, H_{D2} and α_{D2} extends the corresponding function of D_1 with the single exception that $\delta_{D2}(\pi_{D1}(c_{D1}))$ is obtained by appending c_{D2} to the end of $\delta_{D1}(\pi_{D1}(c_{D1}))$, or

3. (Filler rule) $\alpha_{D2}(c_{D2})$ is incompatible with the types assigned to the ancestors of c_{D1}; and $\exists D'_1 < D_2$ with the same nodes as D_1 and the same functions δ, π and α but with $c_{D'1}$ as ancestor of c_{D1} and $c_{D'1}$ is not in $H_{D'1}$.

Define « to be the transitive closure of <, i.e. D « D' iff. there are $D_1, ..., D_n$ such that $D_i < D_{i+1}$, $D = D_1$ and $D' = D_n$. Let 0 be the DAT with a single node o, $\delta_0(o) = < o >$, $\pi_0(o) = o$, $H_0(o) = o$, $c_0(o) = o$ and $\alpha_0(o) = \emptyset$. The class of *wellformed* DATs consists of only those DATs D such that 0 « D.

A DAT-model consists of a set of events E ordered by temporal inclusion ($x \lhd y$ - x is a temporal part of y) and temporal precedence $<$ ($x < y$ - x is earlier than y) , together with an assignment to each T in $TYPE$, of a set of events [[T]] , the extension of T, such that

1. temporal inclusion is a partial order, temporal precedence is a strict partial order and their interaction is constrained by:[8]

    - monotonicity: $x \lhd y < z \Rightarrow x < z$

    - convexity: $x < y < z$ and $x \lhd u$ and $z \lhd u \Rightarrow y \lhd u$

2. maximality: if T is in $TYPE$ and e and e' are in [[T]] and $e' \lhd e$, then $e' = e$.

Maximality ensures that reference to an event is always to a whole 'chunk' of the action.

DATs are interpreted in a model by embeddings with certain conditions. A function f mapping a DAT in a model M is an embedding when:

(i) for every node n, $f(n) \lhd f(\pi_N(n))$

(ii) if n c-commands n', then $f(n) < f(n')$

(iii) $f(n) \models T$, where T is the type labelling n.

A sequence of sentences or text is *interpretable* in a model iff. there is an embedding of a DAT representing its information in that model. The entailment relation is defined on DATs: D_1 entails D_2 iff. every embedding of D_1 into an event model can be extended to an embedding of D_2.

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[8] See van Benthem 1983 for arguments why convexity and monotonicity are the minimal principles governing the event based temporal logic. Overlap is definable (x overlaps with y iff. there is a z that is part of both).

III

FORMALISMS FOR TIME AND SPACE

Fine Grained Theories of Time

Patrick Blackburn*

In the last ten years there has been a fruitful interplay of ideas between philosophical logic and AI, perhaps most notably in the study of logics of belief. In the case of temporal logic, however, the degree of interaction has been relatively minimal. This is rather surprising. Central areas of AI (such as qualitative physics and planning) raise interesting questions about temporal representation and reasoning, and the philosophical tradition (most notably in the modal approach to temporal logic pioneered by Arthur Prior's *tense logic*) has provided detailed maps of temporal logic. Nonetheless, by and large the two fields have gone their own way.

Why should this have happened? An examination of some well known AI temporal representation formalisms, such as those of Allen [1] or McDermott [25] suggests some answers. For a start, both Allen's and McDermott's formalisms are constructed round the ability to refer to times: one names a time and asserts that something holds *at that particular time* — but temporal reference isn't possible in either Priorean or interval based tense logic. In addition, the AI tradition has been concerned with the fact that temporal information comes in a wide variety of types. For example, one of the motives for Allen's approach is to capture the distinction between 'properties', 'events' and 'processes', and more generally a major theme in temporal knowledge representation is building formalisms which mirror such fine grained distinctions. However, while such issues are important in natural language semantics (see, for example Dowty [16]), in the logical tradition they have been rather marginal.

The major contention of the present paper is that this divergence of interests can be straightforwardly overcome. By *sorting* the atomic symbols of various modal languages we will obtain systems in which reference to times is possible, and in which the ontological variety important in AI can be mirrored. Moreover, as an extended case study will show, this sorted modal perspective is a natural one. We'll scrutinise Allen's theory of time first through the eyes of sorted Priorean tense logic, and then via a sorted version of Halpern and Shoham's [24] interval based logic. We'll succeed in capturing all the main ideas of Allen's system, and we'll do so in a fashion that avoids the difficulties that attend his account of properties.

However the paper also has a secondary aim: to explore the idea that natural language semantics can guide the design of knowledge representation formalisms. The fundamental difficulty of applying logic to AI is not so much finding *a* logical representation, but finding the right one. The logical landscape is vast: how do we locate the places of interest? The idea that natural language might be a useful guide is an appealing one, and this paper takes it seriously: none of the sorted systems considered here were developed for use in AI, in fact they originated as attempts to model natural language semantics in a modal framework (see Blackburn [7, 10] and Blackburn and Lascarides [13] for further details). Only subsequently was it observed that the sorting strategies that proved useful in natural language semantics offered an interesting tool for thinking about temporal knowledge representation.

We will proceed as follows. We begin with a brief review of Priorean tense logic, emphasizing its natural language origins and the logical consequences of its design. In the second section we turn to a weakness of Prior's system (its inability to refer to times), and overcome it by sorting. This results in a simple extension of Prior's language in which reference to points and intervals is possible. In the third section we make our first attempt to capture the ideas underlying Allen's theory of time. The attempt is partially successful: we are able to cleanly model Allen's account of

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properties in a decidable system. However, because we are working with a point based semantics, we cannot extend our sorting to deal with Allen's treatment of events. So, in the fourth section we take the obvious step: we apply the sorting strategy to a richer interval based tense logic, the logic of Halpern and Shoham [24]. This permits us to model elegantly model Allen's entire system (though decidability is lost). The paper concludes with some general reflections on the interplay between philosophical logic and AI.

1 Priorean tense logic

What is the 'logic of time' that underlies everyday discourse? Philosophers have given a variety of answers. Quine [32], for example, insists that tenses (and other indexical temporal constructions) should be removed by paraphrase, as the resulting 'eternal sentence' can then be represented in first order logic. According to the Quinean vision, natural language offers no special logic of time of any great interest; tenses are idiosyncracies which conceal the true logical form, a form which is both eternal and extensional. Arthur Prior's vision was the reverse of this. According to Prior, there are interesting logics of time, and the mechanisms by which natural language encodes temporal information deserve serious study. His views led him to develop *tense logic*, a simple intensional language for representing and reasoning about temporal information.

Two main ideas fire Priorean tense logic, and both are abstractions from natural language. The first is syntactic. Prior observed that the tenses of natural language work rather like modal operators. Tenses 'operate' on sentences in non truthfunctional fashion: they insist that the matrix sentence holds at some (possibly different) time. The second idea is semantic. Prior observed that in everyday discourse we take an internal, or observer centred, view of events. Neither past nor future are absolute notions: they make sense only relative to a given time. Tenses, and other temporal indexicals, exploit the fact that everyday discourse is temporally situated: by uttering a sentence we fix a time (namely the utterance time) and natural language typically specifies temporal information relative to this important deictic centre. As we shall see, this semantic intuition is nicely captured in the Kripke semantics of tense logic.[1]

Let's make our discussion precise. A language of (propositional) Priorean tense logic is an ordinary language of propositional calculus augmented by two unary sentence operators F (the *future* tense operator) and P (the *past* tense) operator. That is, Priorean languages contain a denumerably infinite set VAR of distinct propositional variables (written p, q, r and so on), the punctuation symbols (and), some truth functionally adequate collection of Boolean connectives (for example $\wedge$ and $\neg$), and in addition the one place sentence operators F and P.

We make well formed formulas (or sentences) from these symbols as follows. Firstly we stipulate that the set of atomic symbols of the language (hereafter called ATOM) is to be precisely VAR, the set of propositional variables. We then define WFF, the set of well formed formulas of the language to be the smallest set such that: ATOM $\subseteq$ WFF; for all $\phi, \psi \in$ WFF, $(\phi B \psi)$ and $(\neg\phi) \in$ WFF, where B is any binary Boolean operator; and for all $\phi \in$ WFF, $(F\phi)$ and $(P\phi) \in$ WFF. A wff of the form $F\phi$ is read as 'it will be the case that ϕ' (that is, ϕ will hold in the future) and a wff of the form $P\phi$ as 'it was the case that ϕ' (that is, ϕ did hold in the past). We introduce two defined operators G and H, the duals of F and P respectively. $G\phi$ is defined to be $\neg F \neg \phi$ and $H\phi$ is defined to be $\neg P \neg \phi$. $G\phi$ reads 'it is always *going* to be the case that ϕ', and $H\phi$ reads 'it always *has* been the case that ϕ'. Two other syntactic notions will be helpful. By the *degree* of a formula is meant the number of (primitive) logical connectives it contains, and by the *length* of a formula ϕ (written $|\phi|$) is meant the number of primitive symbols it contains.

[1] This sketch does less than justice to Prior's conception. For an detailed (and elegant) exposition one cannot do better than Prior's own writings; the book *Past, Present and Future* [31] is particularly good. Incidentally, it's not historically anachronistic to treat Kripke semantics as if it was part and parcel of Prior's conception. Not only was intuition underlying Kripke semantics clearly shared by Prior, he was also one of the pioneers in its development. As early as 1957 Prior had used what we would now call Kripke models over the frame $\langle N, < \rangle$ (the natural numbers in their usual order); see [30] for further details. For an linguistic survey of tense in natural language, consult Comrie [15].

The semantics of Priorean tense logic is defined in terms of *frames* and *Kripke models*. A frame $\mathbf{T}$ is an ordered pair $\langle T, < \rangle$ where T is a non-empty set, and $<$ is a binary relation on T. The elements of T are thought of as instants (or points) of time and $<$ is to be thought of as the relation of temporal precedence: if $t < t'$ we say that t' is later that t, or t is earlier than t'. In short, frames are a simple set theoretic rendition of a pervasive view of time: that time is rather like a river, a 'flow of temporal elements' from earlier to later. Actually, because we have placed no constraints on the temporal ordering $<$, we're admitting 'flows' that look more like swamps than rivers. No matter. We'll define our semantics in terms of arbitrary frames, but when it comes to applications we shall restrict ourselves to working with a *linear* conception of time. To be more precise, we shall then assume that we are dealing only with frames $\langle T, < \rangle$ that are *strict total orders* (STOs). This means that $<$ must be *transitive* (that is, $\forall t \forall t' \forall t''(t < t' \wedge t' < t'' \rightarrow t < t'')$), *irreflexive* (that is, $\forall t(t \not< t)$), and *trichotomous* (that is, $\forall t \forall t'(t < t' \vee t = t' \vee t' < t)$).[2]

Given a frame $\mathbf{T}$ $(= \langle T, < \rangle)$, a *valuation* V on $\mathbf{T}$ is a function $V : ATOM \longrightarrow Pow(T)$. That is, a valuation assigns to each atom a set of times. The times assigned to a particular atom are thought of as the times where that particular piece of atomic information is true. Valuations link languages with the the flow of time, and we can think of them as dressing a frame in an information distribution. The composite semantic entities known as *models* (or *Kripke models*) are ordered pairs $\langle \mathbf{T}, V \rangle$ where $\mathbf{T}$ is a frame, and V is a valuation on $\mathbf{T}$. If $\mathbf{M} = \langle \mathbf{T}, V \rangle$ is a model, then $\mathbf{T}$ is called the frame *underlying* the model, and we say $\mathbf{M}$ is *based on* $\mathbf{T}$.

We now have all we need to give the satisfaction (or truth) definition for Priorean languages. Let $\mathbf{M}$ be the model $\langle \mathbf{T}, V \rangle$ (that is, $\langle T, <, V \rangle$). We inductively define the three place satisfaction relation $\mathbf{M} \models \phi[t]$, where ϕ is a wff and t is a point of $\mathbf{T}$, as follows:

$$
\begin{array}{lll}
\mathbf{M} \models a[t] & \text{iff} & t \in V(a), \text{ for all atoms } a \\
\mathbf{M} \models \neg\phi[t] & \text{iff} & \mathbf{M} \not\models \phi[t] \\
\mathbf{M} \models \phi \wedge \psi[t] & \text{iff} & \mathbf{M} \models \phi[t] \text{ and } \mathbf{M} \models \psi[t] \\
\mathbf{M} \models F\phi & \text{iff} & \text{there is a } t' \text{ such that } t < t' \ \& \ M \models \phi[t'] \\
\mathbf{M} \models P\phi & \text{iff} & \text{there is a } t' \text{ such that } t' < t \ \& \ M \models \phi[t']
\end{array}
$$

If $\mathbf{M} \models \phi[t]$ then we say that that $\mathbf{M}$ *satisfies* ϕ at t, or ϕ is *true* in the model $\mathbf{M}$ at t. Satisfaction is the fundamental semantic notion, and other useful semantic notions are definable in terms of it. For example, we say that ϕ is *valid in a model* $\mathbf{M}$ iff for all $t \in T$, $\mathbf{M} \models \phi[t]$. We say that ϕ is *valid on a frame* $\mathbf{T}$ iff for all valuations V on $\mathbf{T}$, $\langle \mathbf{T}, V \rangle \models \phi$. That is, a wff ϕ is valid on a frame $\mathbf{T}$ iff it is valid in all models we can construct using $\mathbf{T}$ as the underlying frame, and in such a case we write $\mathbf{T} \models \phi$. A wff is *valid* iff it is valid on all frames $\mathbf{T}$, and in such a case we write $\models \phi$. Finally, we say that a wff ϕ is *satisfiable* iff there is some model $\mathbf{M}$ and a point t of the frame underlying $\mathbf{M}$ such that $\mathbf{M} \models \phi[t]$.

This, then, is Priorean tense logic. It is a syntactically simple language (the complexities of quantifiers, variable binding and substitution have been eschewed in favour of 'implicit quantification' by means of sentence operators) whose semantics builds on an internal perspective on time ($\mathbf{M} \models \phi[t]$, the fundamental notion, relativises truth to the time t). Its syntax to some extent mimics the tenses of natural language, and the relativisation of truths to times built into Kripke semantics gives an elegant handle on one of the most obvious facts about tensed sentences, namely their context dependence.

Now that we know the origin and definition of tense logic, a new question beckons: what exactly is Prior's system when viewed from a logical perspective? The answer, a rather surprising one, emerged in the course of the 1970s: Priorean tense logic can naturally regarded as a fragment of second order logic.[3]

[2] **Actually, various non linear conceptions of time are both interesting and useful; one such conception underlies McDermott's [25] system of temporal knowledge representation, for example. However we're only going to examine Allen's [1] system in the sequel, and Allen treats time as a STO.**

[3] **The detailed development of this answer is due to several logicians, including Thomason [37, 38, 39], Fine [17], Goldblatt [22] and van Benthem [3, 6], and this work remains some of the most interesting ever done in intensional logic. The insight that a second order perspective is needed in intensional logic is a very general one and applies to most modal languages, not just tense logic; though in fact the first modal incompleteness result (which signaled**

The second order nature of tense logic reveals itself when the following question is raised: what constraints on the flow of time can be imposed using by Priorean wffs? Put more simply, what can the Priorean language say about frames? It's straightforward to see that certain first order constraints are expressible. For example, its easy to see that $FFp \rightarrow Fp$ is valid on precisely the frames that are transitive. That is, for any frame $\mathbf{T}$ $(= \langle T, < \rangle)$, we have that $\mathbf{T} \models FFp \rightarrow Fp$ iff $<$ is transitive, and thus we say that $FFp \rightarrow Fp$ *defines* transitivity. As a second example, consider the property of *density* (that is, $\forall t \forall t'(t < t' \rightarrow \exists t''(t < t'' \wedge t'' < t)))$. This is a natural constraint to impose for many applications, and it is definable by means of a Priorean wff: we have that $\mathbf{T} \models Fp \rightarrow FFp$ iff $<$ is a dense relation.

On the other hand some very simple first order constraints on the flow of time are *not* definable using Priorean wffs.[4] In fact we've already met two such conditions: neither irreflexivity nor trichotomy are Priorean definable. Other example abound. Neither *antisymmetry* (that is, $\forall t \forall t'(t < t' \wedge t' < t \rightarrow t = t')$, *asymmetry* (that is, $\forall t \forall t'(t < t' \rightarrow t' \not< t))$, *right directedness* (that is, $\forall t \forall t' \exists t''(t < t'' \wedge t' < t''))$, nor *right discreteness* (that is, $\forall t \forall t'(t < t' \rightarrow \exists s(t < s \wedge \neg \exists s'(t < s' < s))))$ are Priorean definable. These constraints are natural: irreflexivity, antisymmetry and asymmetry forbid various kinds of temporal whirlpools, right directedness points time's river towards the future, trichotomy underlies the linear conception of time, and discrete time models may be the models that best reflect physical reality. In short, regarded as a medium for talking about frames, the Priorean language has some striking first order shortcomings.

Now for the surprise. Although Priorean languages have these first order lapses, they succeed in stepping across the boundary into second order logic: they can express constraints that no first order language can. The following example is due to van Benthem [4]. Let ϕ^Z be the conjunction of the following wffs: $FFp \rightarrow Fp$ (which as has already been mentioned defines transitivity), $P\top \wedge F\top$ (which defines those frames in which there is no first point of time and no last point of time; $\top$ here is shorthand for $p \vee \neg p$), $F(p \wedge q) \rightarrow F(p \wedge Fq) \vee F(p \wedge q) \vee F(q \wedge Fp)$ (this defines those frames in which time doesn't branch to the future), $P(p \wedge q) \rightarrow P(p \wedge Pq) \vee P(p \wedge q) \vee P(q \wedge Pp)$ (this defines those frames in which time does not branch towards the past), and finally this rather mysterious looking wff (actually a bidirectional variant of the Löb formula used in modal provability logic):

$$(H(Hp \rightarrow p) \rightarrow (PHp \rightarrow Hp)) \wedge (G(Gp \rightarrow p) \rightarrow (FGp \rightarrow Hp)).$$

As van Benthem shows, ϕ^Z comes very close to defining $\mathbf{Z}$ $(= \langle Z, < \rangle)$, the set of integers in their usual order, up to isomorphism. To be more precise, he shows that ϕ^Z defines $\mathbf{Z}$ up to isomorphism on the class of connected strict partial orders: that is, the ϕ^Z is valid on a frame $\mathbf{T}$ that is a connected strict partial order iff $\mathbf{T}$ is isomorphic to $\mathbf{Z}$. This is something that cannot be done in first order logic.[5] What is going on?

The magic lies in the variant of Löb's formula. On transitive frames this wff has the effect of demanding that only a *finite* number of points can lie between any pair of points t and t' of the frame. This is a second order constraint, and it is precisely its ability to enforce this property that enables Priorean tense logic to come so close to defining $\mathbf{Z}$ up to isomorphism.

For further discussion of tense logic as second order logic see van Benthem [4]; here I'll merely observe that Prior's strategy has lead in an interesting (and unexpected) direction. By taking cues from natural language he was lead not to a notational variant of known systems, but to a language that combines extreme simplicity with surprising expressive power. Surely such an elegant language must be useful in AI?

the presence of second order phenomenon) was proved (by Thomason [37]) in the setting of Priorean tense logic.

[4] I won't give non definability proofs for any of the following examples, as this would take up too much space. However the examples are all standard, and for a clear discussion and proofs the reader is advised to consult van Benthem [4, 5]

[5] This can be seen as follows. Any first order sentence φ (or indeed, any set Σ of first order sentences) which putatively has the same effect as ϕ^Z has at least one infinite model, namely $\mathbf{Z}$. Thus by the upward Löwenheim Skolem theorem for first order logic φ (or Σ) must have models of every infinite cardinality. The uncountable models cannot be isomorphic to $\mathbf{Z}$.

2 Referential tense logic

In spite of the optimistic concluding words of the previous section, there are obvious obstacles to be overcome before Priorean languages can be usefully applied in AI — indeed, as they stand, Priorean languages are inadequate even for their 'natural application', the logical analysis of natural language.

A particularly obvious shortcoming is the fact that Priorean languages are non-referential. Although one can quantify over past and future times with the aid of F and P, one cannot pick out a particular time and assert that something happened *then*. This is a genuine weakness when it comes to applications in natural language semantics. For example, an utterance of the simple past tense sentence 'I kayaked enthusiastically' doesn't mean that at some completely unspecified past time I did in fact kayak enthusiastically; rather it means that I kayaked at some *particular*, contextually determined, past time.[6] This referential aspect of the simple past tense cannot be mirrored in Priorean languages. The best representation we have for the kayak sentence is $P(I$ *kayak enthusiastically*), and while this correctly places the kayaking in the past, the referential force of the English original eludes it. Although Prior abstracted his system from the natural natural language tend system, formal semanticists tend to regard his abstraction as rather crude, and generally prefer to work with systems such as Kamp's temporal DRT in which temporal reference is possible. The inability to refer is also a drawback in AI. In planning, for example, it's useful to be able to insist that some state of affairs is to hold at some designated time — and indeed most AI temporal representation formalisms are built round mechanisms enabling temporal reference; Allen's HOLDS(P,T) (which says that the property P holds at the time named by T) is fairly typical example.

Faced with this shortcoming we have a choice: abandon Priorean tense logic or extend it to cope with the difficulty. Actually, I think the abandonment option could lead in interesting directions (temporal DRT, for example, seems a promising natural language inspired temporal representation formalism); nonetheless it is the extension option we will explore here.

Now, in extending tense logic we have to be careful not to destroy those features that made it interesting in the first place. Priorean tense logic is a simple system motivated by general features of natural language. It seems sensible to look for extensions that involve minimal tampering with the syntax and semantics of the Priorean original, and to be guided by natural language in our search. One idea that emerges naturally from these desiderata is to *sort* Priorean tense logic.

There is an intuition about natural language along the following lines: different sorts of information comes in different sorts of packets, and knowing what kinds of packets there are, and what types of information they contain, is an important part of knowing a language. To give a simple example, suppose that while Christmas shopping in a crowded department store you overhear a snippet of conversation: '...runs on Sunday...'. You certainly wouldn't be able to tell anybody *what* was running: you didn't hear that part of the conversation, and the topic might have been a person, a train, a program or an egg. Nor could you say *when* the running will take place: certainly on a Sunday, but which one? Indeed no particular Sunday may have been referred to: if the habitual reading of the present tense was intended, the intent may have been to quantify across several Sundays. Nonetheless, as even this discussion of what we don't know shows, we can glean something from the overheard words: minimally that some process (a running) is supposed to take place (either regularly or once) on the day of the week that is neither Monday, Tuesday, ..., nor Saturday. Languages are highly structured entities, and even on the basis of rather minimal input, our knowledge of this structure may enable us to deduce what was (or was not) intended. Part of this structure involves semantic *classifications* and *contrasts*. For example we know that 'Sunday' can be classified as a day-naming-word, and that its denotation contrasts with the denotation of other day-naming-words such as 'Tuesday'. Knowing the various classifications and contrasts and how they are encoded is an important part of knowledge of language, and it is this (rather Saussurean) intuition that I'm going to cartoon in tense logic.

[6] For a discussion of tense, temporal reference, and their interaction (couched in terms of Kamp's temporal DRT) the reader should consult Partee [27].

Sorted first order languages are well understood, but what could be meant by a sorted intensional language? Let's consider the matter. Like all intensional languages, Priorean languages work by manipulating information representations built up using various sentence operators. Ultimately, complex pieces of information are built up out of the atomic symbols. However in Priorean languages, as in other intensional languages, there is only one kind of atomic symbol: propositional variables. Why not introduce a second sort of atomic sentence, syntactically distinct from the first? Indeed, why not introduce a third, a fourth or a fifth new sort of atomic sentence, each distinct from the propositional variables and each other? Syntactically these items would be on a par with the familiar propositional variables: we'd build up sentences using these new symbols, or some mixture of these new symbols and propositional variables, exactly as before. Semantically, however, each sort would be distinct: each sort would embody a different type of information, or to put it another way, each sort would have a different characteristic intended meaning. These characteristic meanings would be captured by placing constraints on the functions that were permitted to interpret the items in each sort: only those functions which respected the intended meaning would be called valuations.

Let's apply this idea to the problem at hand. We'll first add a new sort to Priorean tense logic to make it 'point referential'. So, let NOM, the set of *nominals*, be a set of symbols such that VAR$\cap$NOM$=\emptyset$. We typically represent nominals by the letters i, j, k and so on. Define the set of atoms of our language, ATOM, to be VAR$\cup$NOM. This single atomic level change is the *only* syntactic change we make: the wffs are made up out of the elements of ATOM exactly as for Priorean languages. That is, all atoms are wffs, and we can freely form new wffs from other wffs using the Boolean connectives and tense operators. The only difference is that now the atomic symbols are subdivided into two categories, nominals and propositional variables. Note that the wffs fall naturally into three classes. First there are wffs like $FFp \rightarrow Fp$, which contain only propositional variables. We'll call these *purely Priorean* wffs. Second there are wffs like $i \rightarrow \neg Fi$ which contain only nominals. We'll call these *purely nominal* wffs. Finally there are wffs such as $F(i \wedge p)$ which contain both sorts of atom, and we'll call these *mixed* wffs.

We want nominals to enable us to refer to points of time. To achieve this we're going to insist that in any model, *nominals are to be true at one and only one time*. Nominals will 'name' the unique time they are true at. So, let $\mathbf{T}$ be any frame. By a valuation for our language is meant a function $V : ATOM \longrightarrow Pow(\mathbf{T})$ such that for all $i \in$ NOM, $V(i)$ is a singleton. This atomic level change is the *only* semantic change we make. As with Priorean tense logic we define models $\mathbf{M}$ to be pairs $\langle \mathbf{T}, V \rangle$ where $\mathbf{T}$ is a frame and V a valuation, and we define the concept of a wff ϕ being satisfied in a model $\mathbf{M}$ at a point t (that is, $\mathbf{M} \models \phi[t]$), and the various other semantic notions, exactly as we did for Priorean languages.

Thus we have our first sorted intensional language. The language has two sorts, nominals and variables. The former sort embodies 'single point of time information': on encountering a nominal we may not know what time it names, but we do know that it names some (unique) time. The latter sort we inherited from tense logic; it is an 'arbitrary information sort'. No constraints are placed on the interpretation of variables, and on encountering one we are none the wiser.

What has this sorting achieved? By imposing the constraint on the interpretation of nominals we've broken the 'semantical symmetry' of the atoms and gained expressive power. For example, by writing down the wff

$$P(i \wedge I \textit{ kayak enthusiastically})$$

we can insist not only that we did kayak enthusiastically in the past, but that we did so at a particular time, namely the time named by i. The expressive increase is reflected in a crop of new validities. For example, consider the purely Priorean wff:

$$F(p \wedge q) \wedge F(p \wedge r) \rightarrow F(p \wedge q \wedge r).$$

This is *not* valid. From the information that there is a future time where p and q are true, and also a future time where p and r are true, we cannot conclude that there is a future point where p, q and r are all true together. However the following mixed analog *is* valid:

$$F(i \wedge q) \wedge F(i \wedge r) \rightarrow F(i \wedge q \wedge r).$$

There is only one point at which i is true, so given the truth of the antecedent, the truth of the consequent must follow.

However the expressive gains run deeper: with the aid of nominals we can enforce new constraints on frames. Recall the six examples given earlier of constraints on the flow of time not definable in Priorean languages. All these conditions are definable in our enriched language (indeed, definable using only purely nominal formulas) as the following result shows.

Theorem 2.1 *Let* $\mathbf{T} = \langle T, < \rangle$ *be a frame. Then we have:*

$\mathbf{T} \models i \rightarrow \neg Fi$	*iff*	$<$ *is irreflexive;*
$\mathbf{T} \models i \rightarrow \neg FFi$	*iff*	$<$ *is asymmetric;*
$\mathbf{T} \models i \rightarrow G(Fi \rightarrow i)$	*iff*	$<$ *is antisymmetric;*
$\mathbf{T} \models Pi \vee i \vee Fi$	*iff*	$<$ *is trichotomous;*
$\mathbf{T} \models FPi$	*iff*	$<$ *is right directed;*
$\mathbf{T} \models i \rightarrow (F\top \rightarrow FHH\neg i)$	*iff*	$<$ *is right discrete.*

Proof: Straightforward, and left to the reader. □

Another nice example of the increased expressive power is the following: with the aid of nominals we can define $\mathbf{Z}$, the integers in there usual order, up to isomorphism. We can see this as follows. Let ϕ^{STO} be the following wff:

$$(i \rightarrow \neg Fi) \wedge (Pi \vee i \vee Fi) \wedge (FFi \rightarrow Fi).$$

The first conjunct defines irreflexivity, the second trichotomy, and the third transitivity, thus ϕ^{STO} is valid on precisely the STOs. Now, as has already been discussed, van Benthem has shown that there is a purely Priorean wff ϕ^{Z} which defines $\mathbf{Z}$ on the class of connected strict partial orders. In particular, this means that ϕ^{Z} can distinguish $\mathbf{Z}$ (up to isomorphism) from all the other STOs. But this means that $\phi^{STO} \wedge \phi^{Z}$ is valid on precisely those frames that are isomorphic to $\mathbf{Z}$.

In short, nominals can see temporal structure that propositional variables are blind to. Our sorting has not lead to syntactic sugar, but to some interesting expressive gains. For a fuller discussion of such issues consult Blackburn [8] or Gargov and Goranko [21].

With one referential sort defined, let's turn to another. A great deal of work in both temporal knowledge representation (e.g. Allen [1]) and natural language semantics (e.g. Dowty [16]) insists on the importance of considering extended periods of time, or intervals. We will introduce a third sort, the sort of interval nominals, and constrain their interpretation so that the set of points at which any interval nominal is true forms an interval. Thus, even though we are continuing to work in a point based semantics, we will gain some sort of handle on interval structure. For certain purposes, admittedly, this handle will ultimately turn out to be inadequate, and we'll eventually be forced to sort in the richer setting of interval based semantics. Nonetheless, it's rather interesting to see how far we can go with more modest equipment.

So, let's add this third sort, the sort of *interval nominals*, which will enable us to pick out intervals. First we choose a third denumerably infinite set INOM, mutually disjoint from both NOM and VAR. We write the elements of INOM as e, d, c, and so on, and call them interval nominals. Next we define ATOM to be VAR $\cup$ NOM $\cup$ INOM. Once again, this is the only syntactic change we make: we make wffs from this expanded set of atoms in the usual fashion.

What about the semantics? The following seems a plausible characterisation of what we mean by an interval: *an interval is an unbroken stretch of time.* Let's make this precise. Let $\mathbf{T}$ $(= \langle T, < \rangle)$ be a frame. A *convex* subset of T is a non-empty subset S of T such that $(\forall s, s' \in S)(\forall t \in T)(s < t < s' \Rightarrow t \in S)$. That is, convex subsets are non-empty subsets of frames that are closed under betweenness; that is, unbroken stretches of time.

As we want interval nominals to pick out intervals, we must impose a new constraint on the functions that will count as valuations. Thus we insist that when interpreting our language on a frame $\mathbf{T} = \langle T, < \rangle$, that for all interval nominals e, $V(e)$ must be a convex subset of T. As before, no constraints will be placed on the denotations of variables, and nominals must denote points.

So, let $\mathbf{T}$ be a frame. A function V : ATOM $\longrightarrow Pow(T)$ that respects the three sortal constraints just mentioned is called a valuation, and a model is a pair $\langle \mathbf{T}, V \rangle$ where $\mathbf{T}$ is a frame and V a valuation on $\mathbf{T}$. All the usual semantics concepts such as truth in a model and validity are defined as before. We thus have our second sorted intensional language, a language with three sorts. Let's call this the language of *referential tense logic.*

What can we say with referential tense logic? An important point to observe is that both nominals and interval nominals function very effectively with certain defined operators we have at our disposal, namely the *universal modality* $\Box$ and its dual $\Diamond$. Because we are working with linear time we can define a 'universal modality' $\Box$, such that $\Box\phi$ is true at a time t iff ϕ is true at all times: we need simply define $\Box\phi$ to be $H\phi \wedge \phi \wedge G\phi$. The dual operator $\Diamond$ is thus $\neg\Box\neg\phi$ (that is, $P\phi \vee \phi \vee F\phi$) and clearly $\Diamond\phi$ means 'ϕ is true at some time'. Note the way these two operators interact with our two referential sorts. For example, either $\Box(i \rightarrow \phi)$ or $\Diamond(i \wedge \phi)$ can be regarded as a sort of 'jump' instruction. Because nominals are true at exactly one point, this wff is true iff the information ϕ holds at the point named by i. In effect, the function of these wffs is to shift the point of evaluation to the point named by i and test for the truth of ϕ there. Matters are similar with interval nominals: $\Box(e \rightarrow \phi)$ is true iff the information ϕ holds at all points in the interval named by e. Thus the effect of such wffs is to shift the point of evaluation to the points named by e and run the ϕ test over all of them. As we will see when we apply referential tense logic in AI, such combinations of $\Box$ and $\Diamond$ with the referential sorts are very useful in practice; indeed it's precisely this combination that will enable us to model Allen's HOLDS predicate. Indeed if we wanted to work with referential tensed languages over non-linear time flows — on such flows $\Box$ cannot be defined in terms of the tense operators — it would be an excellent idea to introduce the universal modality as an additional primitive modality. In fact, all the treatments of nominals with which I am familiar have examined the effects of introducing the universal modality as a primitive, precisely because its combination with referential sorts is so effective.[7]

We now have everything we need for our first excursion into temporal knowledge representation, but before applying these tools let's first take stock of where we stand computationally. Has sorting increased the computational complexity of such standard tasks as the satisfiability problem? Pleasantly enough, at least when working with linear time, the answer is no. I'm now going to present a simple argument that shows that the satisfiability problem for the referential tense logic of any class of STOed frames is no worse than the satisfiability problem for the Priorean tense logic of the same class. I'll fo this by (polynomial time) reducing the former problem to the latter. At the heart of the following argument is the following observation: although the language of Priorean tense logic is not referential, it *is* possible (at least when working with linear time), to simulate temporal reference by making use of certain defined operators.

We've already met met two of the defined operators we'll need, namely the universal modality $\Box$ and its dual $\Diamond$. In addition we'll use the *difference* operator D. The difference operator is a modality that explores the inequality relation on frames. That is, $D\phi$ is true at a point t in a model iff ϕ is true at a point t' that is different from t. Because we are working with STOed frames, $D\phi$ is definable: $P\phi \vee F\phi$ suffices. With the help of these operators we can define the two operators that will enable us to simulate referential sorts, the operators U and I.

We define $U\phi$ as follows: $\Diamond(\phi \wedge \neg D\phi)$. Spelling it out, this says that ϕ is true somewhere, but that it is not true anywhere else. That is, ϕ is true at a *unique* point. The U operator will give us a way of simulating nominals. As for $I\phi$, this is defined as follows: $\Diamond\phi \wedge \Box(P\phi \wedge F\phi \rightarrow \phi)$. That is, $I\phi$ is true in a model iff ϕ is true somewhere, and, in addition, the points at which ϕ are true are closed under betweenness. In short, the set of points at which ϕ is true forms an *interval.* Using this operator will give us a means of simulating interval nominals.

We will proceed as follows. We will define, for any wff ϕ of referential tense logic, a corresponding purely Priorean wff $\phi^\flat$ with two pleasant properties. First, the length of $\phi^\flat$ will be

[7] A striking example of this is provided by Seligman's [35] proof theoretic investigation of referential modal languages. He treats the above combination as a primitive, and shows that this enables neat cut elimination theorems and subformula properties to be proved. (Incidentally, Seligman gives this combination a situation theoretic reading: the situation i *supports* the infon ϕ.)

polynomial in the length of ϕ. To put it another way, our translation will be very simple: a computer can rewrite ϕ to ϕ^β in polynomial time. Second, ϕ will be satisfiable iff $\phi^\flat$ is. Thus, given a class of STOs, we will have a method of polynomial time reducing the satisfiability problem of it's referential tense logic to the satisfiability problem of it's ordinary Priorean tense logic.

As a first step we associate each atom of referential tense logic in one-to-one fashion with the propositional variables. So, let β be any bijection from VAR $\cup$ NOM $\cup$ INOM to VAR. We next use β as the base clause for a simple 'substitution translation' σ, which we define as follows: $\sigma(a) = \beta(a)$, for all atoms a; $\sigma(\neg\phi) = \neg\sigma(\phi)$; $\sigma(\phi B\psi) = \sigma(\phi)B\sigma(\psi)$ for all binary Boolean connectives B; $\sigma(F\phi) = F\sigma(\phi)$; and $\sigma(P\phi) = P\sigma(\phi)$. Thus, given a wff of referential tense logic ϕ, $\sigma(\phi)$ is a purely Priorean wff that has exactly the same form as ϕ: all we have done is systematically substitute propositional variables for the atoms in ϕ.

We can now define $\phi^\flat$. Let $i_1, \ldots, i_n$ and $e_1, \ldots, e_m$ be the nominals and interval nominals that occur in ϕ. Then we define $\phi^\flat$ to be:

$$U(\sigma(i_1)) \wedge \cdots \wedge U(\sigma(i_n)) \wedge I(\sigma(e_1)) \wedge \cdots \wedge I(\sigma(e_m)) \wedge \sigma(\phi).$$

If ϕ contains no nominals or interval nominals we simply omit the relevant conjuncts from $\phi^\flat$. Thus, in the special case that ϕ is purely Priorean, $\phi^\flat$ is just $\sigma(\phi)$.

Lemma 2.1 *For any wff ϕ of referential tense logic, $|\phi^\flat|$ is polynomial in $|\phi|$.*

Proof: Obvious. ϕ^β is just the conjunction of $\sigma(\phi)$ with conjuncts of the form $U(\sigma(i))$ and $I(\sigma(i))$. As $|\sigma(\phi)| = |\phi|$, and as the number of conjuncts is determined by the number of nominals and interval nominals in ϕ, the rest is just symbol counting. □

Lemma 2.2 *Let ϕ be any wff of referential tense logic. Then ϕ is satisfiable iff $\phi^\flat$ is satisfiable. Moreover ϕ is satisfiable in a model based on a given frame* **T** *iff $\phi^\flat$ is also satisfiable on a* **T***-based frame.*

Proof: Suppose ϕ is satisfiable. That is, suppose there a model $\mathbf{M} = \langle \mathbf{T}, V\rangle$ and a point t in **T** such that $\mathbf{M} \models \phi[t]$. Let $V^\flat$ be any valuation such that $V^\flat(p) = V(\beta^{-1}(p))$ for all propositional variables p, and let $\mathbf{M}^\flat$ be the model $\langle \mathbf{T}, V^\flat\rangle$. Clearly $\mathbf{M} \models \sigma(\phi)[t]$. (This follows by induction on the degree of ϕ.) Moreover $V^\flat$ assigns singletons and convex subsets to all propositional variables which are β images of nominals and interval nominals respectively. (This follows from the definition of $V^\flat$ in terms of the valuation V.) Thus for all nominals i, $U(\sigma(i))$ is true at all points in $\mathbf{M}^\flat$; and for all interval nominals e, $I(\sigma(e))$ is true at all points in $\mathbf{M}^\flat$. Thus all the conjuncts of $\phi^\flat$ are true in $\mathbf{M}^\flat$ at t, and thus $\phi^\flat$ itself is satisfiable. Note that both **M** and $\mathbf{M}^\flat$ are **T**-based.

Conversely, suppose $\phi^\flat$ is satisfiable. That is, suppose there is a model $\mathbf{M}^\flat = \langle \mathbf{T}, V^\flat\rangle$ and a point t in **T** such that $\mathbf{M}^\flat \models \phi^\flat[t]$. Let V be any function from ATOM to $Pow(\mathbf{T})$ such that (a) $V(\beta^{-1}(p)) = V^\flat(p)$ for all propositional symbols occurring in $\phi^\flat$, (b) $V(i)$ is a singleton, for all nominals i such that $\sigma(i)$ does not occur in $\phi^\flat$, and (c) $V(e)$ is a convex subset for all interval nominals e such that $\sigma(e)$ does not occur in $\phi^\flat$. It is easy to see that any such function V is a valuation. The fact that V obeys the constraints demanded of valuations for all the nominals and interval nominals whose σ image does *not* occur in $\phi^\flat$, follows from clauses (b) and (c) above. The fact that the relevant constraints hold for for all nominals and interval nominals whose σ image *do* occur in $\phi^\flat$ follows immediately from the fact that all the conjuncts of the form $U(\sigma(i))$ and $I(\sigma(e))$ are true in $\mathbf{M}^\flat$. Thus V is a valuation and $\mathbf{M} = \langle \mathbf{T}, V\rangle$ is a model. Clearly $\mathbf{M} \models \phi[t]$. Thus ϕ is satisfiable on a **T**-based model and we are through. □

Theorem 2.2 *Let $\mathcal{S}$ be any class of* STO*s. The problem of determining whether an arbitrary wff of referential tense logic is satisfiable in some* S*-based model, where* $\mathrm{S} \in \mathcal{S}$, *is no harder than the corresponding problem for Priorean tense logic.*

Proof: Suppose we have to determine whether a wff ϕ of referential tense logic is satisfiable in a model based on some STO belonging to class of STOs $\mathcal{S}$. We need merely form $\phi^\flat$ (which by

Lemma 2.1 we can do in polynomial time) and attempt to satisfy $\phi^{\flat}$ on some such model (which by Lemma 2.2 is a necessary and sufficient condition for the satisfiability of ϕ in such a model). But $\phi^{\flat}$ is purely Priorean. $\Box$

As a simple application of this result, we have that the satisfiability problem for the referential tense logic of **Q** ($= \langle Q, < \rangle$), the rational numbers in their usual order, is NP complete. We argue as follows. Clearly this problem is NP hard, as it contains the satisfiability problem for propositional calculus as a special case. On the other hand, the previous theorem tells us that the problem of satisfying Priorean wffs in **Q**-based models gives us an upper bound for the problem. From the work of Ono and Nakamura [26] we know that the problem of satisfying Priorean wffs in **Q** based models is solvable in NP-time. Thus the NP completeness result follows.[8]

I'll close this section with some historical remarks and pointers to the literature on sorted intensional languages and related topics. The idea of introducing nominals to tense logic was considered by Prior [31] in the late 1960s, and the idea was investigated in some detail by Bull [14]. The languages treated in these early papers were more powerful than those considered here: nominals were conceived not so much as sorts, but as variables across points, and explicit quantificational apparatus was introduced for binding them. Nominals as sorts were first introduced by the Sofia school of logic in the setting of Propositional Dynamic Logic (PDL). Passy and Tinchev [28] introduced them to PDL and showed they permitted an elegant treatment of the intersection of programs. Gargov and Passy [19] extended these results to the case of deterministic programs. Finally, Passy and Tinchev [29] is an encyclopeadic examination of nominals in the setting of PDL. Somewhat later, the Sofia school introduced nominals to ordinary modal logic. They make their first appearance in Gargov, Goranko and Tinchev [20]. An important idea introduced in this paper is the use of a non-standard rule of inference (inspired by similar rules in PDL) to prove completeness results. Nominals in the setting of modal logic are systematically investigated in Gargov and Goranko [21]. A beautiful result from this paper is the following: enriching a modal language with D operator results in precisely the same expressive power as enriching a modal language with both nominals and the universal modality.[9] Blackburn [7] considers the effects of introducing nominals and interval nominals to Priorean tense logic and shows how the standard cluster analysis techniques of Segerberg [34] can be applied to obtain completeness and decidability results; many of the results can be found in Blackburn [8]. Blackburn [10] applies nominals to natural language semantics. A Reichenbachian treatment of tense is given, and sorting is also used to handle indexical such as *yesterday*, *today* and *tomorrow*. Nominals also arise naturally in the feature logics inspired by computational linguistics; see Blackburn [9] and Blackburn and Spaan [11, 12] for discussion and technical results. For proof theoretic treatments, Seligman [35] should be consulted. Finally, for a detailed examination of the universal modality the reader should consult Goranko and Passy [23], and for a thorough understanding of the D operator, de Rijke [33] is essential reading.

3 A first look at Allen's system

In this section we make our first attempt to bring together ideas from philosophical logic and AI. We begin by discussing Allen's [1] theory of time, and then attempt to capture its leading ideas in referential tense logic. It will turn out that the combination of tense operators and referential

[8] One warning should be made about Theorem 2.2. The result hinges on the definability of U and I, which in turn hinges on the fact that $\Box$ and D are definable when working with STOs. If we were working on a class of frames in which these operators were not definable, then adding them as primitives *can* have consequences for computational complexity. For example, in Blackburn and Spaan [11, 12] it is shown that the satisfiability problem for multimodal languages with nominals over deterministic frames is NP complete. The universal modality is not definable over this class of frames, and if it as added as a primitive, the satisfiability problem becomes EXPTIME complete.

[9] One direction of this equivalence is obvious: as we saw above, the D operator is strong enough to simulate nominals, and clearly $\phi \wedge \neg D \neg \phi$ defines the universal modality. However the reverse direction is not at all obvious, nor easy to establish. We refer the reader to Gargov and Goranko [21] for further details.

sorts offered by referential tense logic is powerful enough to capture that part of Allen's system concerned with reasoning about properties. On the other hand, because referential tense logic has a point based semantics, his treatment of events will (for the time being) elude us.

3.1 Allen's system

Allen's formalism is a quasi first order language in which various relationships between intervals can be expressed, properties can be asserted to hold over intervals, and events and processes (for which Allen's blanket term is occurrences) can be said to occur at intervals. Let's consider in turn these aspects of his system.

Allen adopts a linear view of time, and he makes use of all thirteen possible relations that can hold between two intervals in an STO. These thirteen mutually exclusive binary relations are the equality relation $=$, and in addition B(efore), M(eets), O(verlaps), S(tarts), D(uring), and F(inishes) and their inverses, $\overline{B}$, $\overline{M}$, $\overline{O}$, $\overline{S}$, $\overline{D}$ and $\overline{F}$. The relations are best introduced by example. Consider the frame $\mathbf{Q}$, the rational numbers in their usual ordering. Then:

$$
\begin{array}{ll}
B([0,1],[2,3]) & \overline{B}([2,3],[0,1]) \\
M([0,1],(1,2]) & \overline{M}([1,2],[0,1)) \\
O([0,2],[1,3]) & \overline{O}([1,3],[0,2]) \\
S([0,1],[0,2]) & \overline{S}([0,2],[0,1]) \\
D([1,2],[0,3]) & \overline{D}([0,3],[1,2]) \\
F([1,2],[0,2]) & \overline{F}([0,2],[1,2])
\end{array}
$$

Allen has a two place relation symbol for talking about each of these relations, thus his language contains such items as BEFORE, MEETS, FINISHES and so on. Axiomatic constraints on the thirteen relations and their interrelationships are stated using this vocabulary. Two typical axioms are:

$$\text{MEETS}(t_1,t_2) \wedge \text{MEETS}(t_2,t_3) \rightarrow \text{BEFORE}(t_1,t_3),$$

and

$$\begin{aligned}&\text{MEETS}(t_1,t_2) \wedge \text{DURING}(t_2,t_3) \rightarrow \\ &\qquad \text{OVERLAPS}(t_1,t_3) \vee \text{DURING}(t_1,t_3) \vee \text{STARTS}(t_1,t_3)\end{aligned}$$

This should give the flavour of Allen's notation for talking about intervals. As is clear from these examples, Allen makes use of the standard Boolean connectives, variables over intervals, and (as we shall see later), the quantifiers $\forall$ and $\exists$. In short, part of his system is a perfectly orthodox first order theory of interval structure.

Allen's then introduces *properties* and *occurrences*. Intuitively, properties P are those states of affairs expressed by such English predicates as 'is blue', 'is hot' and 'is made of cheese'. When we combine a property with a noun phrase we form a property sentence. These sentences have the following characteristic: they can be true at an interval iff they are true over all its subintervals. For example, 'The moon is made of cheese' is true over the interval 2001 A.D. iff 'The moon is made of cheese' is true over all subparts of that year.

Occurrence sentences have quite different temporal characteristics. Allen subclassifies occurrence sentences into event sentences and process sentences; I'm only going to discuss event sentences here. A typical event predicate is 'walked to the store'. Intuitively such a predicate denotes an activity that involves some idea of product, outcome, or culmination. Now consider the event sentence 'John walked to the store', and suppose that T is an interval of time over which John successfully walked to the store. Then if T' is a proper subinterval of T it is *not* true of T' that John walked to the store. There may be other intervals T'' over which John walked to the store — John may walk to the store every Saturday morning, for example — but T cannot contain such T'' and vice versa.

To deal with properties and events Allen introduces two further binary predicates, HOLDS and OCCUR. HOLDS takes a property symbol P and an interval term T, and the resulting expression HOLDS(P,T) asserts that the property P holds over the interval denoted by T. Similarly, OCCUR takes an event symbol E and an interval T, and the resulting expression OCCUR(E,T) asserts that the event E happened over the interval T. These two predicates are governed by axioms which reflect the intuitions about properties and events just discussed. First, Allen demands that:

$$\mathrm{OCCUR}(E,T) \;\&\; \mathrm{IN}(t,T) \Rightarrow \neg\mathrm{OCCUR}(E,t).$$

An event cannot occur at two intervals, one of which is a subinterval of the other. Second, he demands that:

$$\mathrm{HOLDS}(P,T) \Leftrightarrow (\forall t)[\mathrm{IN}(t,T) \Rightarrow \mathrm{HOLDS}(P,t)]$$

where $\mathrm{IN}(t,T)$ is defined as $\mathrm{DURING}(t,T) \vee \mathrm{STARTS}(\mathrm{t},\mathrm{T}) \vee \mathrm{FINISHES}(t,T)$. The truth of a property sentence at an interval trickles down to all proper subintervals.[10]

So far so good. However Allen then goes on to elaborate his account of properties, and at this point his account ceases to be obviously first order. The elaboration concerns the property terms: it turns out that these can have a complex structure, but we're not told exactly what this structure is. We *are* told that property symbols can be combined certain functions named *and*, *or* and *not*, and from the axioms Allen states governing these functions, for example

$$\mathrm{HOLDS}(and(P,Q),T) \Leftrightarrow \mathrm{HOLDS}(P,T) \;\&\; \mathrm{HOLDS}(P,Q)),$$

it's perfectly clear that he wants an 'internal logic' of property terms that mirrors the 'external logic' of formulas. Furthermore, we are told that there is a function *exists* which can bind variables in property terms: evidently property terms contain slots open to some analog of first order quantification. In short, Allen wants to treat properties as term-like entities that behave in a formula-like manner. But this calls for extreme caution. HOLDS is essentially a temporal truth predicate, and such metatheoretic predicates can easily give rise to paradox when coupled with the syntactic freedom that Allen evidently wants. The difficulties can be overcome (Bealer's[2] PRP theory, for example, is one way of doing so) but it is not altogether straightforward, and certainly attention to detail is required. Unfortunately Allen gives neither a syntax nor a semantics for his extensions, and it's never really clear what can and cannot be done in his system.[11]

In spite of these inadequacies Allen's theory has been one of the most influential accounts in AI of temporal representation and reasoning, and certainly its leading intuitions are natural. Can they be captured in referential tense logic? As we shall see, we can successfully capture the ideas that underly Allen's treatment of properties. We'll do so by treating referential tense logic as akin to a low level programming language and define a set of high level macros over it. First we'll define analogs of Allen's interval relating predicates such as MEETS and STARTS. This is easy to do using the referential sorts, and the macros we define automatically inherit the correct logical behaviour from the semantics of referential tense logic. We then define an analog of the HOLDS predicate. This is where our sorting strategy really pays of. In referential tense logic all types of information are treated in syntactically uniform fashion. In particular, referential information (which in a first order setting would be represented using terms) is represented using nominals and interval nominals. But both nominals and interval nominals are just formulas, and can be freely combined using all our logical symbols. In short, an 'internal logic' of reference follows automatically from the semantics of referential tense logic. We bypass completely the tangles that threaten Allen's account of HOLDS.

We'll also learn something negative: we *can't* adequately mirror Allen's idea of an event in referential tense logic. The reasons for the failure will lead us to the idea of sorting in the richer domain of interval based languages, the subject of the following section.

3.2 Simulating Allen's system

Our first task is to show that we can simulate Allen's interval relation symbols. As referential tense logic uses interval nominals to pick out intervals, this means we must show that given two

[10] This is a simplification. Allen also introduces an stronger axiom, $\mathrm{HOLDS}(P,T) \Leftrightarrow (\forall t)[\mathrm{IN}(t,T) \Rightarrow (\exists s)[\mathrm{IN}(s,t) \;\&\; \mathrm{HOLDS}(P,s)]]$. His reasons for doing so aren't relevant to our discussion, and, as Galton [18] shows, this stronger axiom leads to difficulties.

[11] Similar criticisms of Allen's account of properties have been made by Turner [40] and Shoham [36].

interval nominals, say e and d, we can assert than any of the thirteen relations discussed above holds between their denotations. This is easily done. For any interval nominals e and d we define:

$$
\begin{array}{lll}
\textbf{Equals}(e,d) & =_{def} & \Box(e \leftrightarrow d) \\
\textbf{Before}(e,d) & =_{def} & \Box(e \rightarrow \neg d \wedge Fd) \wedge \Diamond(\neg e \wedge \neg d \wedge Pe \wedge Fd) \\
\textbf{After}(e,d) & =_{def} & \Box(e \rightarrow \neg d \wedge Pd) \wedge \Diamond(\neg e \wedge \neg d \wedge Fe \wedge Pd) \\
\textbf{Meets}(e,d) & =_{def} & \Box(e \rightarrow \neg d \wedge Fd) \wedge \neg\Diamond(\neg e \wedge \neg d \wedge Pe \wedge Fd) \\
\overline{\textbf{Meets}}(e,d) & =_{def} & \Box(e \rightarrow \neg d \wedge Pd) \wedge \neg\Diamond(\neg e \wedge \neg d \wedge Fe \wedge Pd) \\
\textbf{Overlaps}(e,d) & =_{def} & \Diamond(e \wedge d) \wedge \Diamond(e \wedge \neg d \wedge Fd) \wedge \Diamond(d \wedge \neg e \wedge Pe) \\
\overline{\textbf{Overlaps}}(e,d) & =_{def} & \Diamond(e \wedge d) \wedge \Diamond(e \wedge \neg d \wedge Pd) \wedge \Diamond(d \wedge \neg e \wedge Fe) \\
\textbf{Starts}(e,d) & =_{def} & \Box(e \rightarrow d) \wedge \Diamond(d \wedge \neg e) \wedge \Box(e \wedge d \rightarrow H(d \rightarrow e)) \\
\textbf{Co-starts}(e,d) & =_{def} & \Box(d \rightarrow e) \wedge \Diamond(e \wedge \neg d) \wedge \Box(d \wedge e \rightarrow H(e \rightarrow d)) \\
\textbf{During}(e,d) & =_{def} & \Box(e \rightarrow d) \wedge \Diamond(d \wedge \neg e \wedge Pe) \wedge \Diamond(d \wedge \neg e \wedge Fe) \\
\textbf{Contains}(d,e) & =_{def} & \Box(d \rightarrow e) \wedge \Diamond(e \wedge \neg d \wedge Pd) \wedge \Diamond(d \wedge \neg e \wedge Fd) \\
\textbf{Finishes}(e,d) & =_{def} & \Box(e \rightarrow d) \wedge \Diamond(d \wedge \neg e) \wedge \Box(e \wedge d \rightarrow G(d \rightarrow e)) \\
\textbf{Co-finishes}(e,d) & =_{def} & \Box(d \rightarrow e) \wedge \Diamond(e \wedge \neg d) \wedge \Box(d \wedge e \rightarrow G(e \rightarrow d))
\end{array}
$$

Though somewhat ungainly, these definitions have the required effect. For example, consider the definition of **Starts**(e,d). The first conjunct asserts that the interval named by e is a subinterval of the interval named by d. The second conjunct guarantees the existence of a time where d is true and e is not, thus the force of the first two conjuncts is that the interval named by e is a proper subinterval of that named by d. Now consider the third conjunct. This says that at any time where both e and d are true, then at all previous times, if d is true, e is true also. To put it another way, we can't find any time t where both e and d are true and such that at some earlier time t' we have d holds and e doesn't. That is, both intervals must start at the same time, and thus the net affect of the three conjuncts captures what is required.

So we can define expressions that correspond straightforwardly to Allen's predicates. Moreover, the logic of these expressions is the logic desired by Allen. For example, consider Allen's axiom

$$\mathrm{MEETS}(t_1,t_2) \wedge \mathrm{MEETS}(t_2,t_3) \rightarrow \mathrm{BEFORE}(t_1,t_3).$$

The macro

$$\textbf{Meets}(e,d) \wedge \textbf{Meets}(d,c) \rightarrow \textbf{Before}(e,c),$$

is a formal analog of this. But this macro is valid. Expanding it into referential tense logic yields:

$$
\begin{array}{l}
\Box(e \rightarrow \neg d \wedge Fd) \wedge \neg\Diamond(\neg e \wedge \neg d \wedge Pe \wedge Fd) \wedge \\
\Box(d \rightarrow \neg c \wedge Fc) \wedge \neg\Diamond(\neg d \wedge \neg c \wedge Pd \wedge Fc) \\
\qquad \rightarrow \Box(e \rightarrow \neg c \wedge Fc) \wedge \Diamond(\neg e \wedge \neg c \wedge Pe \wedge Fc),
\end{array}
$$

which cannot be falsified. In specifying the semantics of referential tense logic we captured Allen's logic of intervals.

Incidentally, if we wanted we could extend these macros to take nominals as well as interval nominals. That is, we could allow ourselves to write down such expressions such as **Before**(i,j), and **Starts**(i,e), where i and j are nominals. **Before**(i,j), which is just

$$\Box(i \rightarrow \neg j \wedge Fj) \wedge \Diamond(\neg j \wedge \neg i \wedge Pi \wedge Fj)$$

says that that point named by i is properly before that named by j; while **Starts**(i,e), which expands into

$$\Box(i \rightarrow e) \wedge \Diamond(e \wedge \neg i) \wedge \Box(i \wedge e \rightarrow H(e \rightarrow i)),$$

says that that point named by i is the earliest point in the interval named by j.

With the first task accomplished, let's turn to the second: mimicking the way Allen's system deals with properties. Can we define a macro **Holds** that has the properties Allen desires of HOLDS? Such a macro must mirror the downwards persistence property:

$$\mathrm{HOLDS}(P,T) \Leftrightarrow (\forall t)[IN(t,T) \Rightarrow \mathrm{HOLDS}(P,t)],$$

and furthermore must possess a suitable 'internal logic'.

The required macro could hardly be simpler. For any wff ϕ and any interval nominal e we define:

$$\mathbf{Holds}(\phi, e) =_{def} \Box(e \rightarrow \phi).$$

In short, **Holds** is just the canonical combination of universal modality and referential sort noted in the previous section. It's clear that it behaves appropriately. First, it satisfies downwards persistence. To see this, let $\mathbf{In}(e,d)$ be defined to hold iff $\mathbf{During}(e,d) \vee \mathbf{Starts}(e,d) \vee \mathbf{Finishes}(e,d)$. A little thought reveals that $\mathbf{In}(e,d)$ holds iff $\Box(e \rightarrow d) \wedge \neg\mathbf{Equals}(d,e)$, and thus (as we would hope) the **In** macro expresses that the interval named by e is a proper subinterval of that named by d. Then for any any interval nominals e and d and any wff ϕ we have that the following expression is valid:

$$\mathbf{Holds}(\phi, e) \wedge \mathbf{In}(d, e) \rightarrow \mathbf{Holds}(\phi, d).$$

We also inherit from the semantics of referential tense languages an internal logic of **Holds** analogous to the internal logic of HOLDS that Allen wants. For example we have that all instances of

$$\mathbf{Holds}(\neg\phi, e) \rightarrow \neg\mathbf{Holds}(\phi, e)$$

and

$$\mathbf{Holds}(\phi \wedge \psi, e) \leftrightarrow \mathbf{Holds}(\phi, e) \wedge \mathbf{Holds}(\psi, e)$$

are valid. In passing, note that we can extend the use of **Holds** to nominals: $\mathbf{Holds}(\phi, i)$, which is just $\Box(i \rightarrow \phi)$ states that the the property ϕ holds at the point picked out by i.

To sum up, referential tense logic captures Allen's calculus of properties in a decidable framework, and does so fairly cleanly. Firstly there's the fairly obvious point that because one can refer to intervals in this language, one can simulate Allen's predicates. Secondly there's the rather more subtle point concerning syntactical uniformity: because information all types of information are handled in uniform fashion we didn't have to introduce somewhat mysterious 'logical functions'; the ordinary connectives sufficed. But now that we've seen what can be simulated, let's turn to what *can't*, namely Allen's treatment of events.

At first sight there seems to be a very appealing way to to model events in referential tense logic. Until now we've used sorting simply as a tool for achieving temporal reference, but couldn't we use it in other ways? In particular, up till now we've followed the Priorean tradition by treating ordinary propositional variables as placeholders for arbitrary information: properties and events are lumped together as things to be represented using propositional variables. So why not enforce sortal constraints here as well? For example, we could subdivide the variables VAR into two syntactically distinct sorts PVAR and EVAR. The elements of the former sort would be taken as ranging over primitive property sentences, and the latter over primitive event sentences. By imposing appropriate constraints on valuations we could hope to capture the distinction and thus model the full scope of Allen's work in an elegant four sorted version of Priorean tense logic.

Unfortunately the idea won't work. It's impossible to state constraints on tense logical valuations that capture Allen's notion of event, as valuations in a point based setting automatically enforce property-like behaviour. Suppose q is an element of EVAR, that is to say, a variable earmarked to represent events. We want to say that q can never be true at two intervals t and t' such that one is a proper subinterval of the other. However in Priorean tense logic, saying that q is true over an interval t amounts to saying that q is true over all points in that interval. This means that if t is not a singleton interval, then q is true over *all* proper subintervals t' of t. Unless we restrict ourselves to the special case of point-events, no constraint on valuations is going to give us what we want: q cannot help but be some sort of property. The point based semantics underlying referential tense logic tense logic is perfect for properties, and this very perfection renders it disastrous for events.

But the very statement of the problem makes the remedy clear. The difficulty has nothing to do with intensional languages *per se*, nor with the idea of sorting: it's simply that a point based temporal semantics is too impoverished support distinctions we wish to draw. So, let's use more appropriate semantic setting. In the following section we'll take as our base a certain interval based language. Sorting this will give us what we want.

4 A sorted interval based language

Interval based languages, like the languages of Priorean tense logic which inspired them, are intensional languages: they contain sentence operators reminiscent of those of Priorean logic, and adopt the internal view of time provided by Kripke semantics. But while they have much in common with Priorean languages there is an important difference: in interval based languages all the fundamental semantic ideas hinge on intervals: valuations assign atomic information to intervals, and wffs are evaluated at intervals. This enables more sophisticated temporal distinctions to be drawn, and in particular, it's going to allow us to model occurrences.

The language we'll sort is an interval based tense logic due to the Shoham and Halpern [36]. This is a very attractive choice: the language is well mapped logically (Shoham and Halpern [24] give general complexity results and Venema [41] a detailed treatment of expressivity and completeness) and when sorted the language has proved to be a natural medium for natural language semantics (see Blackburn and Lascarides [13]). Sorting this language will give us a system of tense logic which can be fairly said to embody Allen's ideas.

Let's begin by assembling our language. The original language of Halpern and Shoham contains the following items: a denumerably infinite collection of propositional variables VAR, whose elements we write as p, q, r and so on, Boolean connectives, the punctuation symbols, and the one place sentence operators $\langle A\rangle$, $\langle\overline{A}\rangle$, $\langle B\rangle$, $\langle\overline{B}\rangle$, $\langle E\rangle$ and $\langle\overline{E}\rangle$. Intuitively, these six operators deal with six of the fundamental relations between intervals in linear time. $\langle A\rangle$ picks out an interval that begins immediately after the current one, while $\langle\overline{A}\rangle$ picks out an interval that finishes immediately beforehand. $\langle B\rangle$ picks out an interval contained in the current one that begins when the current interval begins, while $\langle\overline{B}\rangle$ picks out at interval of which the current one is a beginning. $\langle E\rangle$ and $\langle\overline{E}\rangle$ are analogous to $\langle B\rangle$ and $\langle\overline{B}\rangle$ respectively, but pick out endings instead of beginnings. As we will shortly see, operators picking out intervals related to the current one in any of the other six fundamental ways are definable using these primitives.

The next step is to make this language referential. Let's add two referential sorts: SNOM, the *stretched interval nominals*, and PNOM, the *point-interval nominals*. (To simplify the terminology a bit, we'll usually refer to stretched interval nominals simply as *interval nominals*, and call point-interval nominals *point nominals*.) Stretched interval nominals will be used to name genuinely extended time periods — 'stretched out' periods of time — while point interval nominals will denote certain special point-like intervals. We assume that SNOM and PNOM are denumerably infinite sets, that VAR, SNOM and PNOM are mutually disjoint, represent the elements of SNOM as e, d, c, and those of PNOM by i, j, k and so on.

All the ingredients are in the bowl: now to mix them. Define ATOM to be VAR $\cup$ SNOM $\cup$ PNOM, and let WFF, the set of well formed formulas (or sentences) of our language be the smallest set containing ATOM that is closed under the application of the Boolean and interval operators. We introduce the following defined operators: $\langle D\rangle\phi =_{def} \langle B\rangle\langle E\rangle\phi$, $\langle L\rangle\phi =_{def} \langle A\rangle\langle A\rangle\phi$, $\langle O\rangle\phi =_{def} \langle E\rangle\langle\overline{B}\rangle\phi$, $\langle\overline{D}\rangle\phi =_{def} \langle\overline{B}\rangle\langle\overline{E}\rangle\phi$, $\langle\overline{L}\rangle\phi =_{def} \langle\overline{A}\rangle\langle\overline{A}\rangle\phi$ and $\langle\overline{O}\rangle\phi =_{def} \langle B\rangle\langle\overline{E}\rangle\phi$. As should be clear from the informal readings of the primitive operators, these defined operators correspond to the remaining six relational possibilities that exist between intervals in linear time. For example, $\langle D\rangle$ picks out an interval during the current one, while $\langle O\rangle$ picks out a 'future overlapping' interval. We define the duals of our operators, $[A]$, $[\overline{A}]$, $[B]$, $[\overline{B}]$, $[E]$, $[\overline{E}]$, $[D]$, $[\overline{D}]$, $[L]$, $[\overline{L}]$, $[O]$ and $[\overline{O}]$, in the usual way. For example, $[\overline{E}]\phi =_{def} \neg\langle\overline{E}\rangle\neg\phi$.

Now for the semantics. Following Halpern and Shoham I'll start with an frame (in the usual tense logical sense) and define a concrete set of intervals over it, and I'm going to insist that the frames we start with be strict total orders. So, let $\mathbf{T}$ $(= \langle T, <\rangle)$ be an STOed frame. By $I(\mathbf{T})$ is meant the set of all closed intervals $[t,t']$ $(= \{s \in T : t \leq s \leq t'\})$ on $\mathbf{T}$. We'll call $I(\mathbf{T})$ the intervals of $\mathbf{T}$. The set of intervals on any STOed frame $\mathbf{T}$ decomposes naturally into two disjoint subclasses, $S(\mathbf{T})$ and $P(\mathbf{T})$. $S(\mathbf{T})$ is the set of all those intervals $[t,t']$ such that $t \neq t'$. We call $S(\mathbf{T})$ the *stretched intervals* on $\mathbf{T}$, and they model extended and connected stretches of time — in short, they are 'proper intervals'. $P(\mathbf{T})$ is the set of intervals $[t,t']$ such that $t = t'$, and we call $P(\mathbf{T})$ the point-intervals on $\mathbf{T}$. Clearly such intervals are point-like. They're in 1-1 correspondence with the points of the underlying frame, and indeed when $P(\mathbf{T})$ is equipped with the natural ordering $\prec$, defined by $[t,t] \prec [t',t']$ iff $t < t'$, the resulting frame is isomorphic to the original.

Let's now make use of this structure to interpret our language. Given an STOed frame $\mathbf{T}$, a valuation on $\mathbf{T}$ is a function V with domain ATOM and range $Pow(I(\mathbf{T}))$ that satisfies two constraints. First, for all stretched interval nominals e we insist that $V(e)$ is a singleton, and that if $[t,t']$ is the unique element in $V(e)$, then $[t,t'] \in S(\mathbf{T})$. That is, each interval nominal must denote a unique stretched interval. Second, for all point nominals i we insist that $V(i)$ is a singleton, and that if $[t,t']$ is the unique element in $V(i)$, then $[t,t'] \in P(\mathbf{T})$. That is, each point nominal must denote a unique point interval.[12]

A model $\mathbf{M}$ is a pair $\langle \mathbf{T}, V\rangle$ where $\mathbf{T}$ is a STOed frame and V a valuation on $\mathbf{T}$ of the kind just described. We want to evaluate wffs at intervals, so we inductively define what it is for any model $\mathbf{M}$ $(= \langle T, <, V\rangle)$ to satisfy a wff ϕ at an interval $[t_1,t_2] \in I(\mathbf{T})$:

$$
\begin{array}{lll}
\mathbf{M} \models a[t_1,t_2] & \text{iff} & [t_1,t_2] \in V(a), \text{ for all atoms } a \\
\mathbf{M} \models \neg\phi[t_1,t_2] & \text{iff} & \mathbf{M} \not\models \phi[t_1,t_2] \\
\mathbf{M} \models \phi \wedge \psi[t_1,t_2] & \text{iff} & \mathbf{M} \models \phi[t_1,t_2] \text{ and } \mathbf{M} \models \psi[t_1,t_2] \\
\mathbf{M} \models \langle A\rangle\phi[t_1,t_2] & \text{iff} & \exists t_3 : t_2 < t_3 \text{ and } \mathbf{M} \models \phi[t_2,t_3] \\
\mathbf{M} \models \langle \overline{A}\rangle\phi[t_1,t_2] & \text{iff} & \exists t_3 : t_3 < t_1 \text{ and } \mathbf{M} \models \phi[t_3,t_1] \\
\mathbf{M} \models \langle B\rangle\phi[t_1,t_2] & \text{iff} & \exists t_3 : t_3 < t_2 \text{ and } t_1 \leq t_3 \text{ and } \mathbf{M} \models \phi[t_1,t_3] \\
\mathbf{M} \models \langle \overline{B}\rangle\phi[t_1,t_2] & \text{iff} & \exists t_3 : t_2 < t_3 \text{ and } \mathbf{M} \models \phi[t_1,t_3] \\
\mathbf{M} \models \langle E\rangle\phi[t_1,t_2] & \text{iff} & \exists t_3 : t_1 < t_3 \text{ and } t_3 \leq t_2 \text{ and } \mathbf{M} \models \phi[t_3,t_2] \\
\mathbf{M} \models \langle \overline{E}\rangle\phi[t_1,t_2] & \text{iff} & \exists t_3 : t_3 < t_1 \text{ and } \mathbf{M} \models \phi[t_3,t_2]
\end{array}
$$

We say that a wff ϕ is *valid in a model* $\mathbf{M}$ $(= \langle \mathbf{T}, V\rangle)$ iff $\mathbf{M} \models \phi[t_1,t_2]$ for all $[t_1,t_2] \in I(\mathbf{T})$, and in such a case we write $\mathbf{M} \models \phi$. We say that a wff ϕ is *valid on a frame* $\mathbf{T}$ iff for all valuations V on $\mathbf{T}$, $\langle \mathbf{T}, V\rangle \models \phi$, and in such a case write $\mathbf{T} \models \phi$. If a wff ϕ is valid on all (STOed) frames we say it's *valid* and write $\models \phi$. If ϕ and ψ are wffs such that $\models \phi \leftrightarrow \psi$ then we say that ϕ and ψ are *logically equivalent*.

Let's consider the language more closely. First note that we can define interval analogs of the Priorean operators: for example, stipulating that $F\phi =_{def} \langle A\rangle\phi \vee \langle A\rangle\langle A\rangle\phi$, yields a future tense operator. Next, note that because we're working with a linear conception of time the language is strong enough to define the universal modality. We first define its dual operator:

$$
\begin{array}{lll}
\Diamond\phi & =_{def} & \langle A\rangle\phi \vee \langle \overline{A}\rangle\phi \vee \langle B\rangle\phi \vee \langle \overline{B}\rangle\phi \vee \langle E\rangle\phi \vee \langle \overline{E}\rangle\phi \vee \\
 & & \langle L\rangle\phi \vee \langle \overline{L}\rangle\phi \vee \langle D\rangle\phi \vee \langle \overline{D}\rangle\phi \vee \langle O\rangle\phi \vee \langle \overline{O}\rangle\phi \vee \phi.
\end{array}
$$

That is, a wff $\Diamond\phi$ is true iff it is true at an interval related in one of the thirteen fundamental ways to the interval of evaluation. As any two intervals on an STOed frame must be related in one of these ways, we are entitled to read $\Diamond$ as 'at some interval'. We then define $\Box\phi$ to be $\neg\Diamond\neg\phi$, and read $\Box$ as 'at all intervals'. As we shall see, $\Diamond$ and $\Box$ co-operate with interval nominals and point nominals in the interval framework just as well as they did in the point based setting. Indeed, if we were working with intervals over non-linear time, or with a weaker choice of interval operators in which $\Box$ and $\Diamond$ were not definable, it would be a excellent idea to introduce them as primitives.

Next, note that we can define the D operator. The definition is exactly like that for $\Diamond$, save that (crucially) the ϕ disjunct is not included:

$$
\begin{array}{lll}
D\phi & =_{def} & \langle A\rangle\phi \vee \langle \overline{A}\rangle\phi \vee \langle B\rangle\phi \vee \langle \overline{B}\rangle\phi \vee \langle E\rangle\phi \vee \langle \overline{E}\rangle\phi \vee \\
 & & \langle L\rangle\phi \vee \langle \overline{L}\rangle\phi \vee \langle D\rangle\phi \vee \langle \overline{D}\rangle\phi \vee \langle O\rangle\phi \vee \langle \overline{O}\rangle\phi.
\end{array}
$$

Clearly $D\phi$ holds at an interval iff ϕ holds at some other interval.

[12] It's perhaps worth stressing that we're handling the distinction between interval nominals and point nominals slightly differently from the way did in referential tense logic. In referential tense logic interval nominals could name points. In this language they cannot, as $S(\mathbf{T})$ and $P(\mathbf{T})$ are disjoint. Actually, it might be useful to add a third referential sort in the language — call it INOM — whose members could refer to any interval whatsoever in $I(\mathbf{T})$. Such a referential sort would be rather like interval nominals of referential tense logic. However we'll be content with SNOM and PNOM in this paper.

Now although we won't be using the D operator in the sequel, just as with referential tense logic, the fact that it is definable over STOed frames gives us some information about the complexity induced by our sorting. As before, we first use the D operator to define an operator $U\phi$ that insists that ϕ holds at a unique interval: $\Diamond(\phi \wedge \neg D\phi)$ suffices. Just as in referential tense logic this operator is going to help us to simulate nominals, but we must take care to capture the distinction between point nominals and interval nominals. This is easily done. As Halpern and Shoham observe, for any frame $\mathbf{T}$, $[B]\bot$ is true on precisely the elements of $P(\mathbf{T})$, while $\langle B\rangle\top$ is true on precisely the elements of $S\mathbf{T}$. So, define $U^p\phi$ to be of $U(\phi \wedge [B]\bot)$. $U^p\phi$ insists that ϕ is true at a unique *point* interval, and it enables us to simulate the point nominals. On the other hand, if we define $U^s\phi$ to be $U(\phi \wedge \langle B\rangle\top)$, we have a way of insisting that ϕ is true at a unique stretched interval, and this enables us to simulate interval nominals. Unsurprisingly, by making use of U^p and U^s we can prove an interval based analog of Theorem 2.2: we proceed pretty much as in our discussion of the complexity of referential tense logic. Define β to be a bijection from VAR $\cup$ SNOM $\cup$ INOM to VAR, and, as before, extend this to a substitution translation σ which commutes with all the operators. Then, for any wff ϕ, we define $\phi^\flat$ to be:

$$U^p(\sigma(i_1)) \wedge \cdots \wedge U^p(\sigma(i_n)) \wedge U^s(\sigma(e_1)) \wedge \cdots \wedge U^s(\sigma(e_m)) \wedge \sigma(\phi),$$

where $i_1, \ldots, i_n$ and $e_1, \ldots, e_m$ are all the point nominals and interval nominals that occur in ϕ. Analogs of Lemma 2.1 and Lemma 2.2 are easily proved, and this leads to:

Theorem 4.1 *Let $\mathcal{S}$ be any class of* STOs. *The problem of determining whether an arbitrary wff of referential interval based logic is satisfiable in an* **S**-*based model, where* $\mathbf{S} \in \mathcal{S}$, *is no harder than the corresponding problem for the system of Halpern and Shoham.* □

There is, however, a difference: in the interval based setting 'no worse' generally means undecidable, for as Halpern and Shoham show, their language has an undecidable satisfaction problem for most interesting classes of frames.

On the other hand, the expressivity of our sorted system is delightful. Unsurprisingly the language is strong enough analogs of Allen's favoured vocabulary. In fact, as the operators are tailored to express exactly the relationships Allen isolated, by making use of our referential sorts we can simulate Allen's system much more simply and elegantly than in referential tense logic. In the following definitions r and r' are metavariables over both interval nominals and point nominals.

$$\begin{array}{lll}
\mathbf{Equals}(r,r') & =_{def} & \Box(r \leftrightarrow r') \\
\mathbf{Before}(r,r') & =_{def} & \Box(r \rightarrow \langle L\rangle r') \\
\mathbf{After}(r,r') & =_{def} & \Box(r \rightarrow \langle \overline{L}\rangle r') \\
\mathbf{Meets}(r,r') & =_{def} & \Box(r \rightarrow \langle A\rangle r') \\
\overline{\mathbf{Meets}}(r,r') & =_{def} & \Box(r \rightarrow \langle \overline{A}\rangle r') \\
\mathbf{Overlaps}(r,r') & =_{def} & \Box(r \rightarrow \langle O\rangle r') \\
\overline{\mathbf{Overlaps}}(r,r') & =_{def} & \Box(r \rightarrow \langle \overline{O}\rangle r') \\
\mathbf{Starts}(r,r') & =_{def} & \Box(r \rightarrow \langle \overline{B}\rangle r') \\
\mathbf{Co\text{-}starts}(r,r') & =_{def} & \Box(r \rightarrow \langle B\rangle r') \\
\mathbf{During}(r,r') & =_{def} & \Box(r \rightarrow \langle \overline{D}\rangle r') \\
\mathbf{Contains}(r,r') & =_{def} & \Box(r \rightarrow \langle D\rangle r') \\
\mathbf{Finishes}(r,r') & =_{def} & \Box(r \rightarrow \langle \overline{E}\rangle r') \\
\mathbf{Co\text{-}finishes}(r,r') & =_{def} & \Box(r \rightarrow \langle E\rangle r')
\end{array}$$

The effect of these definitions should be clear: if both r and r' are instantiated in interval nominals, the resulting expression makes the same assertion about the two named intervals as does the use of Allen's corresponding predicate. For example, **Before**(e, d) is true in any model $\mathfrak{M}$ iff the unique stretched interval denoted by e properly precedes that denoted by d. Note that if we instantiate at least one of r and r' in point nominals, the macros extend Allen's terminology to express relationships between a point and an interval, or between two points. Of course, not all of the expressions are meaningful in such cases, but all the incorrect uses are weeded out by the semantics. For example, **Overlaps**(i, j) is logically equivalent to $\bot$; our semantics (quite correctly) insists that we are talking nonsense.

Just as with referential tense logic, the force of Allen's axioms is captured by the semantics of our language. For example, corresponding to Allen's axiom:

$$\begin{aligned}&\mathrm{MEETS}(t_1, t_2) \wedge \mathrm{DURING}(t_2, t_3) \rightarrow \\ &\qquad \mathrm{OVERLAPS}(t_1, t_3) \vee \mathrm{DURING}(t_1, t_3) \vee \mathrm{STARTS}(t_1, t_3),\end{aligned}$$

we can write down macros of the form

$$\mathbf{Meets}(e, d) \wedge \mathbf{During}(d, c) \rightarrow \mathbf{Overlaps}(e, c) \vee \mathbf{During}(e, c) \vee \mathbf{Starts}(e, c).$$

Expanding such a macro yields:

$$\Box(e \rightarrow \langle A \rangle d) \wedge \Box(d \rightarrow \langle \overline{D} \rangle c) \rightarrow \Box(e \rightarrow \langle O \rangle c) \vee \Box(e \rightarrow \langle \overline{D} \rangle c) \vee \Box(e \rightarrow \langle \overline{B} \rangle c),$$

which is easily seen to be a validity.

Let's consider the HOLDS predicate. This can be mimicked as follows:

$$\mathbf{Holds}(\phi, e) =_{def} \Box(e \rightarrow \phi \wedge [D]\phi \wedge [B]\phi \wedge [E]\phi).$$

Once more, **Holds** is just the universal modality cooperating with the referential sorts.

Actually, we can do a little more. For reasons that need not detain us here, Galton [18] suggests that not one but *three* variants of the HOLDS predicate are needed: HOLDS-AT(P, I), which asserts that the property P holds at the instant I, HOLDS-IN(P, T), which asserts that the property P holds at some instant during the interval T, and HOLDS-ON(P, T), which asserts that the property P holds at every instant during the interval T. It's clear how to simulate the HOLDS-AT operator: **Holds-at**$(\phi, i) =_{def} \Box(i \rightarrow \phi)$ suffices. However it's not quite so obvious how to simulate the HOLDS-IN and HOLDS-ON predicates. Certainly it would be a simple task if we had a 'point finding' operator $\langle \dagger \rangle$, defined as follows, at our disposal:

$$\langle \mathbf{T}, V \rangle \models \langle \dagger \rangle \phi[t', t''] \text{ iff } (\exists [t, t] \in P(\mathbf{T}))([t, t] \subseteq [t', t''] \;\&\; \langle \mathbf{T}, V \rangle \models \phi[t, t]).$$

If we had such an operator we could then simulate the HOLDS-IN predicate as follows:

$$\mathbf{Holds\text{-}in}(\phi, e) =_{def} \Box(e \rightarrow \langle \dagger \rangle \phi),$$

and, using the dual operator $[\dagger]$ of $\langle \dagger \rangle$, we could mimic the HOLDS-ON predicate:

$$\mathbf{Holds\text{-}on}(\phi, e) =_{def} \Box(e \rightarrow [\dagger]\phi).$$

In fact $\langle \dagger \rangle$ is already available as a defined operator. First (as Halpern and Shoham observe), we can define a 'beginning point' operator $\mathbf{[}BP\mathbf{]}$ as follows:

$$\mathbf{[}BP\mathbf{]}\phi =_{def} ([B]\bot \wedge \phi) \vee \langle B \rangle([B]\bot \wedge \phi).$$

That is, $\mathbf{[}BP\mathbf{]}\phi$ is true at an interval t iff ϕ is true at the point that begins t. In similar fashion, we can define and 'end point' operator:

$$\mathbf{[}EP\mathbf{]}\phi =_{def} ([E]\bot \wedge \phi) \vee \langle E \rangle([E]\bot \wedge \phi).$$

Using these we can define $\langle \dagger \rangle \phi$ as follows:

$$\langle \dagger \rangle \phi =_{def} \mathbf{[}BP\mathbf{]}\phi \vee \mathbf{[}EP\mathbf{]}\phi \vee \langle D \rangle \mathbf{[}BP\mathbf{]}\phi,$$

and the dual $[\dagger]\phi$ is handled analogously.

To sum up, once more we have a system which embodies the ideas underlying Allen's treatment of properties. Indeed, the interval based language simulates Allen's property calculus rather elegantly, (certainly the required macros are on the whole simpler than with referential tense logic) and is also capable of modelling the refinements of Allen's idea suggested by Galton.

But what about events? In the previous section we suggested imposing sortal constraints on the propositional variables to mirror the difference between properties and events. This idea couldn't be carried out, however, because the point based semantics automatically enforced property like behaviour. This doesn't happen in interval based semantics: it can perfectly well happen that $t_1 < t_2 < t_3 < t_4$ and that p is true over $[t_1, t_4]$ but false over $[t_2, t_3]$. Indeed there is a sense in which sorting is practically forced on us in interval based logic: without some constraints on valuations we have no guarantee that *any* of our propositional variables behave like properties or events. The information distributions possible in the interval based setting can be truly wild, thus if we don't want the blooming buzzing confusion of a Humean universe, we must impose order ourselves.

So let's do this. Subdivide VAR into two mutually disjoint and denumerably infinite sets, PVAR and EVAR. We call the elements of PVAR *property variables* and we'll represent its elements by p, p_1, p_2, p_3 and so on, and we'll call the elements of EVAR *event variables* and represent them by q, q_1, q_2, q_3 and so on. The definition of the wffs of our language is unchanged. We have precisely the same atoms as before — VAR ∪ INOM ∪ SNOM — and we build the wffs out of them as we used to. As usual, the only syntactic difference occurs at the atomic level.

Now for the semantics. Given an STOed frame **T**, by a *PE-sorted valuation* V on **T** is meant a valuation that satisfies two further constraints.

$$(\forall p \in PVAR)(\forall \mathbf{i} \in I(\mathbf{T}))(\mathbf{i} \in V(p) \Leftrightarrow (\forall \mathbf{i}' \in I(\mathbf{T})(\mathbf{i}' \subset \mathbf{i} \Rightarrow \mathbf{i}' \in V(p))))$$
$$(\forall q \in EVAR)(\forall \mathbf{i}, \mathbf{i}' \in I(\mathbf{T}))(\mathbf{i} \in V(q) \ \&\ \mathbf{i}' \in V(q) \ \&\ \mathbf{i} \neq \mathbf{i}' \Rightarrow \mathbf{i} \cap \mathbf{i}' = \emptyset))$$

We then define *PE-sorted models* to be models whose valuations are PE-sorted. The satisfaction definition, and all the usual semantic definitions are exactly as before.

With these definitions we reach our goal. This four sorted version of Halpern and Shoham's logic captures the major ideas underlying Allen's framework: one can refer to times in it (both points and intervals), Allen's major ontological divide (between properties and events) is reflected in it, and it gives an unproblematic logic of HOLDS.

5 Discussion

In this paper we have established a link between the temporal logical traditions of philosophical logic and AI. We have seen that it is possible to capture in tense logic intuitions important in temporal knowledge representation, and it should be clear that the sorting mechanism that made this possible lends itself to further experimentation. For example, following Blackburn [10] or Blackburn and Lascarides [13] one could sort to capture the effect of such temporal indexicals as *now*, *yesterday today* and *tomorrow* or the parphernalia of day-names and dates. One could also sort to capture richer ontological distinctions than Allen's simple dichotomy between properties and events: the list given in Shoham [36] provides a useful starting point. Moreover, obvious technical extensions beckon: one could introduce variables over any (or all) of the sorts and explicitly quantify them. Such *hybrid languages*, incidentally, aren't *terra incognita*: both Bull's [14] early investigations and Seligman's [35] proof theoretical work provide useful guides. Thus, within the terms it has set itself, the paper has succeeded. However, to close this paper I think it is appropriate (and perhaps salutory) to address the question of just how interesting these self imposed terms actually are. To put the matter bluntly, while a link between the two temporal logical traditions may now be clearer, is this of any relevance to the *practice* of AI?

Many readers of this paper will have a feeling of *déja vu*. Those with an AI background will have encountered a jungle of temporal representations formalism, and may question the utility of devising yet another. Those with logical backgrounds will realise that there is an endless variety of languages in which the ideas of this paper could be expressed. For example, by applying the ideas of correspondence theory (cf. van Benthem [4, 5]) one could easily carry out the present paper's suggestions in first or second order languages. One might find the simplicity of the modal formalisms attractive, and approve of the influence of natural language and yet suspect that the languages defined here only add to the confusion.

To such objections, at any rate, a response can be given. As I said at the start of the paper, the real difficulty in applying logic in AI is not finding *a* logical representation, but finding a good one. Precisely because the logical terrain is so vast, some sort of map is needed. Viewing the problems of temporal representation through the eyes of relatively modest systems (such as the tensed languages explored here) is interesting because it can sometimes reveal hidden pockets of simplicity. We've seen one example of this. By thinking about reference to intervals in a point based system (namely referential tense logic) we were able to capture the main ideas of Allen's property calculus in a decidable framework. Similarly, it is certainly not the case that ideas from natural language semantics provide the only way of thinking about temporal knowledge representation; rather, the point is that navigating the space of representations is difficult. A flexible approach that makes use of all available insights is called for, and, as we have seen, natural language influenced formalisms can at least offer novel perspectives on temporal representation.

But while this answer is satisfactory as far as it goes, it cannot be denied that such high level approaches to the problems of AI provide at most a half-way house. Further questions are pressing. For example, given a temporal logical representation formalism, are there useful tractable fragments? Further, if a problem is known to be intrinsically difficult, can conditions under which tractability problems are avoidable be characterised? While such questions can often be settled on a case by case basis, it is unclear whether interesting general answers exist. The questions are highly application dependent: what is a useful fragment in one application may be totally inappropriate in another.

In short, at present it is unclear what role (if any) logic can play in settling such issues. Perhaps the only interesting answers here are engineering answers, and logic's task is the (relatively modest) one of providing a conceptual framework for formalism design. Nonetheless, it would certainly be interesting see more sustained attempts to bridge the gap between logical theory and AI practice: conceivably this could give rise to a subject with stronger claims to the title 'applied logic'.

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Generalizing Allen's calculus: chain calculi

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Abstract The calculus of time intervals defined by Allen has been extended in various ways in order to accomodate the need for considering other time objects than convex intervals (eg.time points *and* intervals, non convex intervals). This paper introduces and investigates the calculus of chains (or generalized intervals), which subsumes these extensions, in an algebraic setting. The set of (p,q)-relations, which generalizes the set of relations in the sense of Allen, has both an order structure and an algebraic structure. We show that, as an order, it is a distributive lattice whose properties express the topological properties of the set of (p,q)-relations. We also determine in what sense the algebraic operations of transposition and composition act continuously on this set.

In Allen's algebra, the subset of relations which can be translated into conjunctive constraints on the endpoints using only $<,>,=,\leq,\geq$ has special computational significance (the constraint propagation algorithm is complete when restricted to such relations). We give a geometric characterization of a similar subset in the general case, and prove that it is stable under composition. As a consequence of this last fact, we get a very simple explicit formula for the composition of two elements in this subset.

1. Introduction

In [Vil82], Marc Vilain describes a logic for reasoning about time which is an extension of the logic defined by James Allen [All83]. Specifically, it is at its core composed of 13 relational primitives (Allen's relations) and of a body of inference rules (Allen's "transition table"). Moreover, it is extended to a logic which besides relations between two intervals, can also handle relations between two time points, or relations between a point and an interval. As concerns this extension, Vilain comments : "We should state that including [points] along with intervals in the domain of our system only minimally complicates the deduction algorithms. The polynomial complexity results and the consistency maintenance remain unaffected". In other words, allowing basic time objects to be either time intervals or time points does not alter in a significant way the framework of Allen's logic.

Ladkin [Lad86] introduced the notion of non convex temporal intervals and gave a taxonomy of important relations between them. He also argued for the convenience of a language based on non convex intervals in such applications as the specification of concurrent processes.

An interval in the sense of Allen is just a pair of ordered time points. A non convex interval (with a finite number of convex components) is entirely determined by the sequence of pairs associated to each convex component. Hence a non convex interval is determined by an ordered sequence of an even number of time points.

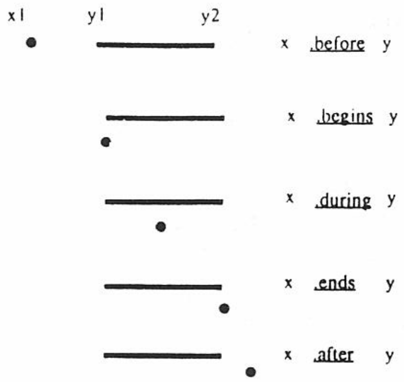

Fig. 1 : Some of Vilain's point-to-interval relations

In the standard terminology, a chain is a totally ordered set. Clearly, all the temporal objects mentioned above can be represented by finite chains. We also call a (finite) chain with n points a n-chain. More generally, for any subset S of the integers, a S-chain is a n-chain where n belongs to S. In this way, Allen's calculus is the calculus of 2-chains; Vilain's universe is the set of {1,2}-chains. The calculus of non convex intervals in the sense of Ladkin is the calculus of P-chains, where P is the set of even integers.

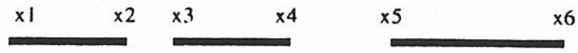

Fig. 2: A non convex interval

Allen's calculus is basically algebraic in nature. Ladkin and Maddux [LaMa87b, LaMa88] showed that it can be adequately described using the notion of a relation algebra as defined by Tarski and Jonsson [JoTa52]. Specifically, consider the set $\Pi(2,2)$ of 13 possible relations between two intervals. The set of subsets of $\Pi(2,2)$ is a Boolean algebra with additional structure, in particular, a transposition is defined on it, as well as an operation of composition (described by the transition table). This additional structure makes it an integral relation algebra A(2). The connexion between this algebra and the models of Allen's logic can be established using the algebraic notion of a weak representation, which generalizes the classical notion of a representation, as shown in [Lig90c].

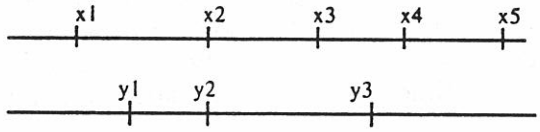

Fig. 3: Chains

A well known theorem of Cantor states that the ordered set of the rational numbers **Q** is up to isomorphism, the only denumerable total order which is both dense and unlimited on the left and on the right. This can be seen as a result about the calculus of points, or about the representations of the relation algebra A(1) associated to the set $\Pi(1,1)$ of 3 possible relations between two points: up to isomorphism, A(1) has only one denumerable representation. Ladkin [Lad87b] proved that a similar fact is true of A(2). In [Lig90c], we show that these two results are just the n=1 and n=2 cases of a quite general result: for any $n \geq 1$, **A**(n) has only one denumerable representation up to isomorphism, where A(n) is the representation algebra associated to the calculus of n-chains.

But this is only part of the story. Consider again Allen's transition table, which gives the result of the composition of two primitive relations. Firstly, only 26 relations appear in it, among the 2^{13} possibilities in A(2). Then, as remarked by many people [Noe88, LiBe89a], there is a notion of neighbourhood between relations, which corresponds to the physical intuition of small moves of the intervals considered. For example, if an interval i meets another interval j, we can move i slightly to the right, and then i overlaps j; or to the left, and then i < j.

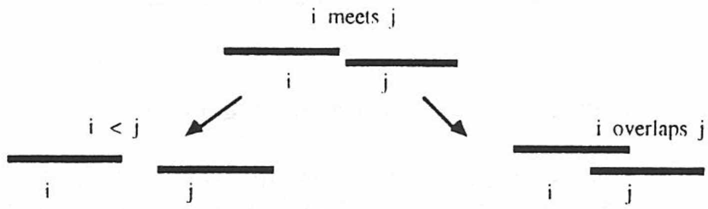

Fig. 4: Neighbouring relations

Hence, relation m (meets) in some sense has o (overlaps) and < as immediate neighbours. In [LiBe89a, Lig90b] we describe how the topological structure of the set of relations in Π(2,2) can be conveniently represented by a polygon; essentially the same picture (a lattice) was known to [Noe88]. Finally, the transition table makes apparent the fact that composition has some kind of continuity property: composing neighbouring relations, we tend to get neighbouring sets of results.

This is a first motivation for understanding more about the topology of relations. A further motivation is concerned with its computational relevance.

Allen's original publications described a polynomial algorithm for determining the consistency of a temporal network, ie. a graph of intervals with arcs labeled by elements of A(2). This algorithm was known not to be complete. Subsequently, Vilain and Kautz [ViKa86] showed that the problem in the general case is NP-complete.

However, restricting the labeling to a small subset of A(2) (83 elements) makes Allen's algorithm complete, as shown in [vBeek89, vBC90, ViKa86]. This subset can be defined as the set of relations which can be expressed as a conjunction of convex conditions on the endpoints of the intervals; or equivalently, it is the set of intervals in the lattice associated to Π(2,2). This last characterization makes apparent the topological nature of this set of well behaved elements.

In this paper, we will be concerned both with the algebraic and the topological aspects of the calculus of chains. As the preceding discussion shows, giving this more general framework allows us to discuss in a unified way a whole body of results about representing and reasoning about time. The main purpose of the paper is to give a precise content to the remarks made above, by

- giving formal definitions of the interval algebras and their associated objects;
- proving the main facts about the algebraic and topological structures and the relationships between algebra and topology .

2. Generalizing Allen's relations: (p,q)- relations

2.1. (p,q)-relations

Definition Let T be a total order. A n-chain in T is an increasing sequence $x = (x_1, x_2, \ldots, x_n)$ of elements of T :

$$x_1 < x_2 < \ldots < x_n.$$

Let $x = (x_1,...,x_p)$ be a p-chain, $y = (y_1,...,y_q)$ a q-chain in a total order T. The points $y_1, y_2, ..., y_q$ define a partition of T into 2q+1 zones in T, which we number from 0 to 2q (Fig.5):

zone 0 is $\{t \in T \mid t < y_1\}$; zone 1 is y_1;

zone 2 is $\{t \in T \mid y_1 < t < y_2\}$; etc. ... zone 2q is $\{t \in T \mid t > y_q\}$.

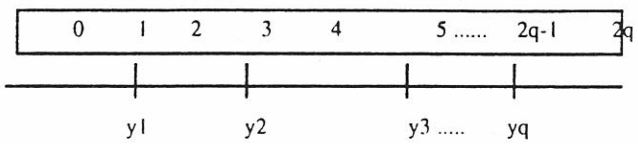

Figure 5 : The partition of T determined by a q-chain.

Now the relation of x relative to y is entirely determined by specifying for each x_i which zone it belongs to; a constraint is that each oddly numbered zone contains one of the x_i's at most. This motivates the following:

Definition The set $\Pi(p,q)$ of (p,q)-relations is the set of non-decreasing sequences π of p integers between 0 and 2q, where each odd integer occurs at most once.

Remark In [Lig90c] we give another equivalent definition of the set of (p,q)-relations; it has the advantage of being more symmetrical; however, the present definition makes the order structure of this set more obvious.

Examples (i) $\Pi(1,1)$ has 3 elements 0, 1,2, corresponding respectively to x <y, x=y, y<x.

(ii) $\Pi(1,2)$ has 5 elements 0, 1, 2, 3, 4; using the terminology of Vilain in [Vil82], we can call them respectively .before, .begins, .during, .ends, .after . On the other hand, $\Pi(2,1)$ also has 5 elements, namely (0,0), (0,1), (0,2), (1,2), (2,2); in Vilain's notation, these are called before., ended-by., contains., begun-by., after., respectively. (More generally, exchanging the roles of x and y, we see that $\Pi(p,q)$ and $\Pi(q,p)$ contain the same number of elements; more about this later).

(ii) $\Pi(2,2)$ has 13 elements, namely Allen's primitive relations; in particular, (1,3) is equality; six elements are the following (the remaining ones are obtained by switching roles between x and y):

(0,0) = <	(before)	(0,1) = m	(meets)	(0,2) = o	(overlaps)
(2,2) = d	(during)	(2,3) = e	(ends)	(1,2) = s	(starts)

Figure 6: Some of Allen's relations

2.2. Associated inequations

Each element π in $\Pi(p,q)$ corresponds to a set of equations and inequations $E(\pi)$:

$$(1) \quad \text{for } i=1,...,p \quad E(\pi) \quad \begin{cases} x_i = y_{(\pi(i)+1)/2} & \text{if } \pi(i) \text{ is odd;} \\ x_i > y_{\pi(i)/2} & \text{if } \pi(i) \text{ is even, } \pi(i) < 2q; \\ x_i < y_{(\pi(i)+2)/2} & \text{if } \pi(i) \text{ is even, } \pi(i) > 0. \end{cases}$$

As a consequence, any subset of $\Pi((p,q)$ corresponds to a formula in the language with equality with variables $x_1,..., x_p$, $y_1,..., x_q$ and predicate "<". We extend this language with $>, \leq, \geq$, considered as abbreviations.

3. The order structure of (p,q)- relations

3.1. The lattice of (p,q)-relations We have defined the set of (p,q)-relations as a subset of $\mathbf{N}\times \ldots \times \mathbf{N}$ (p times); hence the product order on $\mathbf{N}\times \ldots \times \mathbf{N}$ defines an order on $\Pi(p,q)$, namely:

Definition Let π, π' be two elements of $\Pi(p,q)$; then $\pi \leq \pi'$ if and only if
$\pi(i) \leq \pi'(i)$ for $i=1, \ldots,p$.

Proposition $(\Pi(p,q), \leq)$ is a distributive lattice.

Proof A product of total orders is a distributive lattice. The sup and inf of two elements can be computed componentwise. $\Pi(p,q)$ is a subset of such a product which contains sup's and inf's.

Again because of its very construction, $\Pi(p,q)$ is a subset of $\mathbf{R}^p$; we can consider its Hasse diagram, which is by definition the graph with $\Pi(p,q)$ as its set of vertices, where an arc joins π to π' if π' is an immediate successor of π. In this way, the Hasse diagram of H(p,q) is naturally embedded into $\mathbf{R}^p$. Figure 7 represents H(1,1), H(1,2), H(2,1), H(2,2). Intuitively, two relations are neighbours if passing from one to the other only involves changing the relation of one pair (x_i,y_j).

We claim that H(p,q) (with its canonical embedding in $\mathbf{R}^p$) gives an adequate representation of the topology of (p,q)-relations.

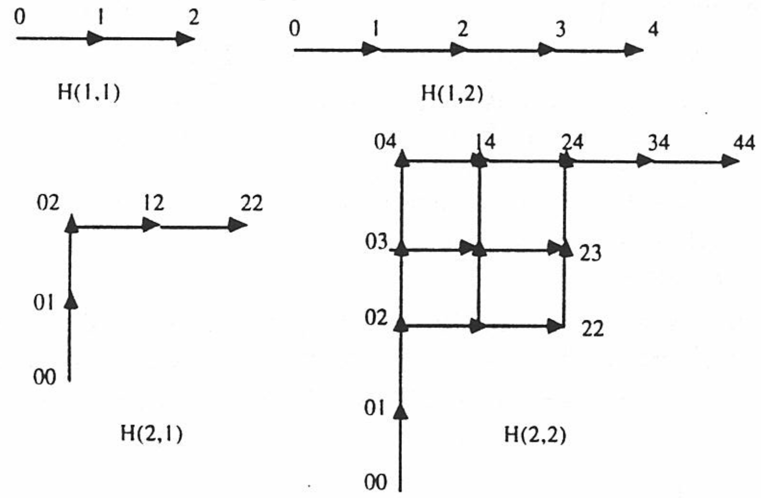

Figure 7 : Hasse diagrams

3.2. Characterizing the intervals in $\Pi(p,q)$

Recall that in any lattice L, an interval is any subset of the form $I(l_1,l_2) = \{l \in L \mid l_1 \leq l \leq l_2\}$ where $l_1 \leq l_2$ are two elements of L. The central theme in this section will be the set of intervals in $\Pi(p,q)$. We first give a characterization of the set of intervals in terms of inequations.

Proposition The set of intervals in $\Pi(p,q)$ coincides with the set of subsets associated to conjunctions of formulas $x_k \psi y_s$, where $\psi \in \{=, <, >, \leq, \geq\}$.

Proof By definition of $\Pi(p,q)$, we have

$$
(2)\qquad
\begin{array}{lll}
\pi(k) = 2s - 1 & \text{if and only if} & (x_k = y_s); \\
\pi(k) = 2s & \text{if and only if} & (y_s < x_k < y_{s+1})\ (s \neq 0, 2q); \\
\pi(k) = 0 & \text{if and only if} & x_k < y_1; \\
\pi(k) = 2q & \text{if and only if} & y_q < x_k.
\end{array}
$$

Hence each one of formulas (a,b,c,d,e) defines the subset of π's verifying a corresponding condition:

$$
\begin{array}{lll}
(a)\ x_k = y_s & \text{defines} & \{\pi \mid \pi(k) = 2s - 1\}; \\
(b)\ x_k < y_s & \text{defines} & \{\pi \mid \pi(k) \leq 2s - 2\}; \\
(c)\ x_k > y_s & \text{defines} & \{\pi \mid \pi(k) \geq 2s\}; \\
(d)\ x_k \leq y_s & \text{defines} & \{\pi \mid \pi(k) \leq 2s - 1\}; \\
(e)\ x_k \geq y_s & \text{defines} & \{\pi \mid \pi(k) \geq 2s - 1\}.
\end{array}
$$

Obviously, the subsets defined in $\Pi(p,q)$ by (a,b,c,d,e) are intervals in $\Pi(p,q)$; hence any subset defined by a conjunction of such formulas is an interval.
Conversely, it suffices to show that any interval of the form

$I_{p,q}(k,[m,n]) = \{\pi \mid \pi(k) \in [m,n]\}$ is defined by such a formula.

By (2), $\pi(k) \in [m,n]$ is equivalent to

$$
\begin{array}{ll}
y_{m/2} < x_k < y_{(n+2)/2} & \text{if } m,n \text{ are even;} \\
y_{(m+1)/2} \leq x_k < y_{(n+2)/2} & \text{if } m \text{ is odd, } n \text{ is even;} \\
y_{m/2} < x_k \leq y_{(n+1)/2} & \text{if } m \text{ is even, } n \text{ is odd;} \\
y_{(m+1)/2} \leq x_k \leq y_{(n+1)/2} & \text{if } m,n \text{ are odd;}
\end{array}
$$

(we use the convention to leave out the inequations involving y_0 or y_{q+1}; e.g. $y_0 < x_k < y_{(n+2)/2}$ is replaced by $x_k < y_{(n+2)/2}$).
The general result follows from this fact.

This result generalizes what was essentially known for $\Pi(2,2)$; intervals are called "convex relations" in Nökel [Noe88]. The algorithmic properties of the set of intervals in $\Pi(2,2)$ are examined in van Beek [vBeek89, vBeek90] and van Beek and Cohen [vBC90].

4. Operations and intervals

4.1. Operations on $\Pi(p,q)$

Transposition As already remarked, switching roles between x and y sends a (p,q)-relation π to a (q,p)-relation π^t. We give a precise description of this operation, which is called transposition:

Definition Let π be an element of $\Pi(p,q)$. Then $\pi^t \in \Pi(q,p)$ is defined as follows:

Consider the first q odd integers $1, 3, \ldots, 2q-1$; call $\mathrm{odd}(i) = 2i - 1$ the i-th odd number; consider each odd(i) in sequence, and position it in the sequence $\pi(1), \ldots, \pi(p)$:

if $\mathrm{odd}(i) < \pi(1)$, then $\pi^t(i) = 0$;

if $\pi(p) < odd(i)$, then $\pi^t(i) = 2p$;
if $odd(i) = \pi(j)$, then $\pi^t(i) = 2j-1$;
if $\pi(j) < odd(i) < \pi(j+1)$, then $\pi^t(i) = 2j$.

Proposition Transposition is an order reversing bijection from $\Pi(p,q)$ onto $\Pi(q,p)$.

Proof Using the definition, it is easily shown that if π' is an immediate successor of π, then π'^t is an immediate predecessor of π^t.

Examples Fig. 8 resp. Fig 9 illustrates the correspondance between H(1,2) and H(2,1), resp. H(2,3) and H(3,2).

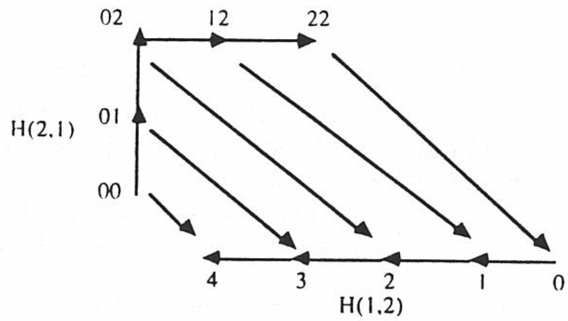

Figure 8

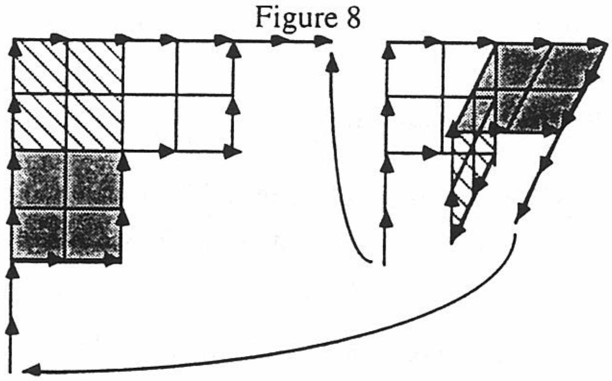

Figure 9

Composition If a p-chain x is in relation π relative to a q-chain y, and y itself is in relation π' relative to a r-chain z, there is a finite number of elements in $\Pi(p,r)$ representing the possible relations of x relative to z. Translating this fact into our notations, we arrive at the definition of composition. In order to express it conveniently, we need the following:

Notation If $m \leq n$ are two integers, $[[m,n]]$ denotes $[m,n]$ if m and n are even, $[m+1,n]$ if m is odd, n is even, $[m,n-1]$ if m is even, n is odd, $[m+1, n-1]$ if both m and n are odd (in other words, we leave out the odd endpoints).

Convention For any $\pi \in \Pi(s,t)$, $\pi(0) = 0$; $\pi(i) = 2t$ if $i > s$.

Definition Let $\pi \in \Pi(p,q)$, $\pi' \in \Pi(q,r)$. Then $(\pi;\pi')$ is the set of elements $\pi'' \in \Pi(p,r)$ such that, for every j, $1 \leq j \leq p$:

$\pi''(j) = \pi'((\pi(j)+1)/2)$ if $\pi(j)$ is odd;

$\pi''(j) \in [[\pi'(\pi(j)/2), \pi'((\pi(j)+2)/2)]]$ if $\pi(j)$ is even.

Examples (i) Take $\pi=\pi'= (0,2) \in \Pi(2,2)$ (the o = "overlaps" relation); since $\pi(1)$ and $\pi(2)$ are even, we get the set of π'' such that:

$\pi''(1) \in [[\pi'(0),\pi'(1)]] = [[0,0]] = 0;$

$\pi''(2) \in [[\pi'(1),\pi'(2)]] = [[0,2]] = [0,2];$

hence $(\pi;\pi')$ is the set $\{(0,0),(0,1),(0,2)\} = \{<,m,o\}$.

(ii) Take $\pi= (2,3)$, $\pi'= (3,4) \in \Pi(2,2)$; then

$\pi''(1)$ is $\in [[\pi'(1),\pi'(2)]] = [[3,4]] = 4;$

$\pi''(2) = \pi'(2) = 4;$

hence $(\pi;\pi')$ is the set reduced to $(4,4)$ (the ">" relation).

Remark The above definition clearly shows that, for $\pi \in \Pi(p,q)$ and $\pi' \in \Pi(q,r)$, $(\pi;\pi')$ is an interval in $\Pi(p,r)$. In other words, the entries in the corresponding transition table are intervals. Moreover, they are intervals of a special kind: their projection on each component is either an integer or an interval with even boundaries.

In particular, the entries in Allen's transition table should be of this type. Checking all possibilities, we get a set of 28 intervals among which 26 do appear in the transition table.

We show in the next section that this fact is only a particular aspect of the stability of intervals with respect to composition.

4.2. Stability of the set of intervals

We first extend composition to sets in a natural way:

Definition Let E, F be subsets of $\Pi(p,q)$, $\Pi(q, r)$ resp. Then we denote by (E;F) the union of all $(\pi;\pi')$, where $\pi \in \Pi(p,q)$ and $\pi' \in \Pi(q,r)$. In the same manner, E^t is the set of π^t, where $\pi \in E$.

The interaction of composition with transposition is described by:

Proposition For all $\pi \in \Pi(p,q)$, $\pi' \in \Pi(q,r)$,

$(\pi;\pi')^t = (\pi'^t;\pi^t)$.

The next proposition expresses the fact that composition is non decreasing relative to its arguments:

Proposition If $\pi \le \pi_1$, $\pi' \le \pi'_1$ then :

(a) $\inf(\pi;\pi') \le \inf(\pi_1;\pi')$ and $\sup(\pi;\pi') \le \sup(\pi_1;\pi')$; hence

(b) $\inf(\pi;\pi') \le \sup(\pi_1;\pi'_1)$.

Proof Suppose π_1 is an immediate successor of π; then all components of π and π_1 coincide, except for one; let i_0 such that $\pi_1(i_0) = \pi(i_0) + 1$. Then the definitions of $(\pi;\pi')$ and $(\pi_1;\pi')$ only differ on their i_0-th components : if $\pi(i_0) = m$ is odd, we get $\pi'((m+1)/2)$ for $(\pi;\pi')$ and $[[\pi'((m+1)/2), \pi'((m+3)/2)]]$ for $(\pi_1;\pi')$; if $\pi(i_0) = m$ is even, we get

$[[\pi'(m/2), \pi'((m+2)/2)\ ]]$ for $(\pi;\pi')$ and $\pi'((m+2)/2)$ for $(\pi_1;\pi')$; in all cases, $\inf(\pi;\pi') \leq \inf(\pi_1;\pi')$, and $\sup(\pi;\pi') \leq \sup(\pi_1;\pi')$; hence

$$\inf(\pi;\pi') \leq \sup(\pi_1;\pi').$$

A similar, easier reasoning works for the right argument; (alternatively, transposition can be used to deduce the result from the preceding one). By induction, we get the general result.

We now state the main result about stability:

Proposition The set of intervals is stable by intersection, transposition, and composition.

The last statement means that, if I in $\Pi(p,q)$ and J in $\Pi(q,r)$ are two intervals, then (I;J) is an interval in $\Pi(p,r)$.

Proof The part about intersection and transposition is obvious. For composition, we use the more precise

Lemma Let $I_{p,q}(k,[m,n]) = \{\ \pi \mid \pi(k) \in [m,n]\}$; then

$$I_{p,q}(k,m)\ ;\ \pi' = \begin{cases} I_{p,r}(k,\ \pi'((m+1)/2) \text{ if m is odd;} \\ \\ I_{p,r}(k,\ [[\pi'(m/2),\ \pi'((m/+2)/2), \text{if m is even.} \end{cases}$$

Putting together the preceding results, we get an explicit formula for computing the composition of two intervals:

Theorem Let $[\alpha,\beta]$ be an interval in $\Pi(p,q)$, $[\gamma,\delta]$ an interval in $\Pi(q,r)$; then

$[\alpha,\beta]\ ;\ [\gamma,\delta]$ is the interval $[\ \inf(\alpha;\gamma),\ \sup(\beta,\delta)]$ in $\Pi(p,r)$.

Proof Since $[\alpha,\beta]\ ;\ [\gamma,\delta] \supseteq (\alpha;\gamma)$, $\inf(\alpha;\gamma) \in [\alpha,\beta]\ ;\ [\gamma,\delta]$. The same holds for $\sup(\beta,\delta)$. Since is an interval, $[\alpha,\beta]\ ;\ [\gamma,\delta] \supseteq [\ \inf(\alpha;\gamma),\ \sup(\beta,\delta)]$. Conversely, let $t \in (\pi;\pi')$, for $\pi \in [\alpha,\beta]$, $\pi' \in [\gamma,\delta]$. Since $\alpha \leq \pi$ and $\gamma \leq \pi'$, we have $\inf(\alpha;\beta) \leq \inf(\pi;\pi') \leq t$. In the same way, we show that $t \leq \sup(\beta,\delta)$.

5. Chain calculus as algebra

5.1. Constructing relation algebras

We now look in more detail at the algebraic structure of $\Pi(p,q)$.

Notations For $p \geq 1$, $\mathbf{1'}_{p,p}$ denotes equality in $\Pi(p,p)$, i.e. the element in $\Pi(p,p)$ such that $\mathbf{1'}_{p,p}(i) = \text{odd}(i)$, $1 \leq i \leq p$.

If E is a set, $\mathcal{P}(E)$ denotes the set of subsets of E.

Proposition The following properties obtain, for any $\pi_1 \in \Pi(p,q)$, $\pi_2 \in \Pi(q,r)$ and $\pi_3 \in \Pi(r,s)$:

i) $((\pi_1\ ;\ \pi_2)\ ;\pi_3) = (\pi_1\ ;(\pi_2\ ;\ \pi_3))$;

ii) $(\pi_1\ ;\ \mathbf{1'}_{q,q}) = \pi_1$ and $(\mathbf{1'}_{p,p}\ ;\pi_1\ ) = \pi_1$;

iii) $\mathbf{1'}_{p,p} \in (\pi_1\ ;\ \pi_1{}^t\ )$ and $\mathbf{1'}_{q,q} \in (\pi_1{}^t\ ;\ \pi_1\ )$;

iv) $\pi \in (\pi_1\ ;\ \pi_2\ )$ implies $\pi_1 \in (\pi\ ;\ \pi_2{}^t\ )$ and $\pi_2 \in (\pi_1{}^t\ ;\ \pi\ )$;

v) $(\pi_1 ; \pi_2)^t = (\pi_2^t ; \pi_1^t)$.

Let S be a non empty subset of the positive integers. In order to construct the relation algebra A(S) which describes the calculus of S-chains, we proceed as follows:

- firstly, we take the union of all (p,q)-relations $\Pi(p,q)$, where $(p,q) \in S \times S$: $\Pi(S) = \bigcup_{(p,q)\in S\times S}\Pi(p,q)$;

- composition extends to $\Pi(S)$, with values in $\mathcal{P}(\Pi(S))$, in the following way :

if $\pi_1 \in \Pi(p,q)$, $\pi_2 \in \Pi(p',q')$, then if $q=p'$, $(\pi_1 ; \pi_2)$ is the same set of elements of $\Pi(p,q')$ as defined before, considered as elements of $\Pi(S)$; else, it is $\emptyset$ (the empty set);

- transposition is globally defined on $\Pi(S)$;

– the union of unit elements $\mathbf{1}'_{p,p}$, for $p \in S$, is an element $\mathbf{1}'_S$ of $\mathcal{P}(\Pi(S))$:

$$\mathbf{1}'_S = \{\mathbf{1}'_{p,p} \mid p \in S\}$$

The proposition implies that $\Pi(S)$, together with composition, transposition and $\mathbf{1}'_S$, is a connected groupoid in the sense of Comer [Com83, Def. 3.1]; if S has one element, this polygroupoid is in fact a polygroup. Still using [Com83], this can be expresed equivalently in terms of relation algebras in the sense of Tarski [JoTa52]:

Let $A(S) = \mathcal{P}(\Pi(S))$; it is a boolean algebra; besides, it inherits an unary operation of transposition, a binary operation of composition, and a distinguished element $\mathbf{1}'_S$. Then:

Theorem A(S) is a simple, complete, atomic relation algebra, with $0 \neq 1$. It is integral if and only $S = \{n\}$, for some $n \geq 1$.

Remark More generally, we can define $\Pi(S)$, hence A(S), in the case where S is an equivalence relation on a subset of N^+. In this way, we get algebras which are not necessarily simple. For instance, if S is the partition $\{1\},\{2\}$ of $\{1,2\}$, we get an algebra with 26 atoms which is defined in [LaMa88] in terms of constraint networks.

Examples

(i) A(1) has 8 elements, which can be identified to the subsets of $\Pi(1,1)$; identifying the elements 0,1,2 of $\Pi(1,1)$ with >, δ (equality), > resp., we see that the elements of A(1) are <, δ,>, $\leq$ (ie. $< + \delta$),$\geq$ (ie. $> + \delta$),$\neq$ (ie. $< + >$),0 (the empty set), and **1** (ie. $< + > + \delta$). The structure of A(1) is entirely determined by the effect of transposition on < (it exchanges <and >), and by the conditions

$$(< ; <) = <, \quad (< ; >) = \mathbf{1}.$$

(ii) A(1,2) is an algebra with 26 atoms, which are the elements of

$$\Pi(1,1) \cup \Pi(1,2) \cup \Pi(2,1) \cup \Pi(2,2).$$

Its structure is determined by the effect of transposition, which operates on $\Pi(1,1)$ as described above, on $\Pi(2,2)$ (which is the set of atoms of Allen's algebra) and exchanges $\Pi(1,2)$ and $\Pi(2,1)$, and by composition, which is as described by Allen's transition table and Vilain's extension.

In the general case, A(S) describes the calculus on n-chains, where $n \in S$.

5. 2. Using the algebra : weak representations

Temporal reasoning in AI deals with temporal databases consisting of sets of time objects; a basic problem consists in proving and maintaining the consistency of such a database; we now sketch how the algebraic machinery allows us to define such databases as algebraic structures.

Definition A weak representation of a relation algebra A is a map Φ of A into a direct product of algebras of the form subsets-of($U \times U$) , such that:

(a) Φ defines a homomorphism of boolean algebras;

(b) $\Phi(1') = \{(u,u) \mid u \in U\}$.

(c) $\Phi(^t) = {}^t$ (transposition of a binary relation)

(d) $\Phi(\alpha ; \beta) \supseteq \Phi(\alpha) \circ \Phi(\beta)$.

This notion is an extension of the classical notion of a representation, which is defined as a weak representation satisfying :

(e) Φ is one-to-one;

(f) $\Phi(\alpha ; \beta) = \Phi(\alpha) \circ \Phi(\beta)$.

If A is a relation algebra, we shall say that a weak representation of A into subsets-of($U \times U$) is connected if $\Phi(\mathbf{1}) = U \times U$ (**1** denotes the greatest element in the underlying boolean algebra).

Examples

(i) A connected weak representation of A(1) is defined by the following data :

- a non empty set U (call its elements time points);
- a binary relation $R = \Phi(<)$ on U.

In fact, because of (b), the image of equality has to be $\Delta = \{(u,u) \mid u \in U\}$; because of (c), $\Phi(>)$ is the transpose R^t of R.

These data are subject to the following conditions:

by (a) and connectedness, $\{R, R^t, \Delta\}$ is a partition of $U \times U$; hence R is irreflexive and total; by (d), we have $R \supseteq R \circ R^t$. But this is just transitivity for R.

In other words, R defines a total order on U. This shows that the notion of a connected weak representation of A(1) is equivalent to that of a total order.

Representations of A(1) have to satisfy the further conditions :

$$R \circ R \supseteq R;$$
$$R \circ R^t \supseteq R;$$
$$R^t \circ R \supseteq R.$$

It is easily verified that the first condition expresses the fact that R is dense; the second one, that U is unlimited on the right; the third one, that U is unlimited on the left. Hence a representation of A(1) is a total order which is dense and unlimited in both directions. By a theorem of Cantor, any denumerable order having these properties is isomorphic to the order of the rational numbers **Q**. We show in [Lig90] that this result generalizes to representations of A(n) for any $n \geq 1$.

(ii) Weak representations of A({1,2}) Consider such a representation Φ, with underlying set U. Then $\Phi(\mathbf{1}'_{1,1}) = \{(u,u) \mid u \in U^1\}$, $\Phi(\mathbf{1}'_{2,2}) = \{(u,u) \mid u \in U^2\}$. The sets U^1 and U^2 are time points and time intervals respectively.

For example, Fig. 10 represents a weak representation with $= \{u_{1,}\}$, $= \{u_2,u_3\}$ which corresponds to the specifications:

$\Phi(o) = \{(u_2,u_3)\}$	(o denotes (0,2) in $\Pi((2,2))$;
$\Phi(\underline{.during}) = \{(u_1,u_2)\}$	(<u>.during</u> denotes 2 in $\Pi((1,2))$;
$\Phi(\underline{.before}) = \{(u_1,u_3)\}$	(<u>.before</u> is denotes in $\Pi((1,2))$.

Figure 10 : A weak representation of A({1,2})

In applications, we have sets of constraints which can be represented as networks with arcs labeled by elements of A(S), where S is some set of integers. The preceding discussion gives a framework for maintaining and checking the consistency of such a network. It also implies that restricting the labels to the subsets of intervals guarantees the completeness of the constraint propagation algorithm.

6. Conclusion We have introduced a calculus of (p,q)-relations which provides a framework subsuming a number of formalisms used in temporal reasoning. Investigating the partial order structure of the set of positions allowed us to characterize in a simple way an important subset of positions: the subset of intervals; we related this subset to the operations of composition and transition, and obtained a simple explicit expression for the composition of two intervals. We also gave a precise definition of the algebraic basis of this generalized calculus, and showed how results on the computational feasability of consistency checking can be extended to this wider framework.

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TEMPS ET INTENTION POUR UNE THEORIE FORMELLE DE L'ACTION: ASPECTS LOGIQUES

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Abstract

We present the system we have called CIT (*Croyance, Intention et Temps* [Belief, Intention, and Time]) which is intended as an approach to the inner logic of an agent, on the basis of its (his,her) beliefs, intentions, goals and desires, with an explicit treatment of time. All the modal operators for propositional attitudes incorporate time and agent parameters.

The relationship between intention and belief will be discussed along the paper, and especially, the approaches proposed by Cohen-Levesque and Shoham about it. We will propose an axiomatics for intention and belief incorporating time and agent parameters, which is sound w.r.t the semantics determined by ETS-I-S-structures.

1. Introduction.

L'idée du temps joue un rôle central dans presque tous les domains de l'Intelligence Arificielle (IA), notamment en ce qui concerne l'analyse du changement. Le besoin d'une représentation acceptable du temps, de la connaissance temporelle et des variations temporelles des états mentaux, ayant pour object la capacité de raisonner par la suite, a donné lieu à la naissance d'un sous-domain spécifique en IA qui est connu comme celui du *raissonnement temporel*. Son but n'est autre que trouver des représentations et des mécanismes d'inférence pour les propositions temporelles, de sorte qu'il y ait un équilibre sufisant entre la force expressive du système de représentation et les exigences d'efficacité du mécanisme inférentiel. A la limite, il s'agit d'étudier la structure temporelle, dans un sens renouvelé par rapport aux travaux traditionnels en logique temporelle ((pri67), (reuk71), (vbe83), (gol87)).

L'avantage de l'approche logique (et nous ne nous bornons pas à la logique classique du premier ordre) est fondé dans la double condition de la logique en tant que langage et en tant que calcul. Le langage logique a une syntaxe bien définie et une sémantique très claire du point de vue mathématique. Pour ce qui est du calcul, l'inférence est relativement simple et il est facile de garantir la correction et la consistance du système axiomatique envisagé, et parfois il est de même possible prouver la complétude et quelques résultats intéressants concernant sa complexité computationelle.

Raisonner sur le changement au cours du temps oblige à choisir entre une perspective praxéologique directe avec temps implicite et une perspective praxéologique indirecte avec temps explicite. Le calcul des situations de McCarthy and Hayes (mcha69) et les logiques dynamiques (mises en place par Pratt, (pra76)) se situent dans la première perspective. Les logiques temporelles de Allen, McDermott et Shoham dans la seconde ((all83), (all84), (mcd82), (sho88)).

Dans les lignes qui suivent nous ne pouvons pas traiter in extenso sur les avantages et les inconvénients de chacune de ces deux approches. Ceci dit, nous faisons un choix pour le traitement explicite du temps dans la mesure où ce choix nous permet d'offrir une représentation plus claire de la durée, des actions simultanées et des actions qu'intersèctent, ouvrant la voie - s'il en faut- à des formalismes temporels non-monotones dans les bases d'une théorie formelle de l'action confrontée aux problèmes de la qualification et de la prédiction. Bien évidemment , l'insistance sur l'explicitation du temps laisse dans un niveau dérivé l'intuition immédiate de l'agent qui change l'état du monde par son action.

2. Le système CIT (croyance, intention et temps)

Il s'agit d'une logique modale de la croyance et de l'intention qui veut rendre compte de la logique interne d'un agent ayant des ressources limitées et des besoins de coordination, et par conséquent suivant des plans. (bra87) propose une étude philosophique approfondie de l'intention, qui peut être utilisée en psychologie cognitive et en IA. Il est vrai que sur la base de cette logique CIT nous pouvons intégrer d'autres logiques partielles pour d'autres attitudes propositionnelles, mais nous ne le ferons pas dans ce texte.

Nous traitons le temps d'une manière classique, dans le cadre de la logique du premier ordre; donc, nous ne suivons pas les formalismes modaux bien connus en logique temporelle. L'idée de base consiste à associer un paramètre à toute variable propositionnelle et par la suite considérer dans la sémantique de Kripke un monde possible comme une entité traversée par le temps.

Nous estimons que le temps doit être formalisé de la façon la plus générale possible et qu'ensuite les divers systèmes spécifiques doivent faire le choix pour une "ontologie" précise (temps discret ou continu, temps instantané ou par intervalle, temps linéaire ou ramifié). La seule spécification que nous considérons concerne le caractère instantané du temps, afin de présenter une version très simple du système CIT. Bien entendu, la sémantique du système est un peu plus complexe dans le cas d'un temps par intervalles (sho88).

Syntaxe temporelle

Alphabet

L'alphabet $\mathcal{A}$ est défini comme l'union des ensembles suivants:

1- VP = $\{p_1, p_2, p_3 ....\}$: Ensemble infini dénombrable de variables propositionnelles.

2- CT = $\{ct_1, ct_2, ct_3 ....\}$: Ensemble infini dénombrable de constantes temporelles.

3. VT = $\{vt_1, vt_2, vt_3 ....\}$: Ensemble infini dénombrable de variables temporelles.

4- Deux symboles de relation: $\equiv$, $\leq$.

5. L'ensemble des connecteurs: $\{\rightarrow, \neg\}$

6. Le quantificateur $\forall$.

Ensemble d'expressions bien formées (ebf-s)

(1) Si p est une variable propositionnelle et $t \in CT \cup VT$, alors p^t est une ebf.

(2) Si $t_i \in CT \cup VT$ et $t_j \in CT \cup VT$, alors $(t_i \equiv t_j)$ et $(t_i \leq t_j)$ sont des ebf-s.

(3) Si A et B sont des ebf-s, alors $(\neg A)$ et $(A \rightarrow B)$ sont des ebf-s.

(4) Si A est une ebf et $vt_i \in VT$, alors $\forall vt_i A$ est une ebf.

sémantique temporelle

Une structure U est définie de la façon suivante:

$U =_{def} < T, \leq , =, M>$.

- T est un ensemble non vide. Nous l'appelerons ensemble d'instants temporels, et il est le domain d'interprétation des constantes et des variables temporelles.

- $\leq \subseteq T^2$ est un ordre partiel defini dans T.

- $= \subseteq T^2$ est la relation d'égalité.

- $M =_{def} <M_1 , w>$, où

M_1: CT --> T, une application de CT dans T.

w: VP --> 2^T, une application de VP dans l'ensemble de tous les sous-ensembles de T.

Avec M_1 nous interprétons les constantes temporelles comme instants temporels de T. w associe à chaque variable propositionnelle un ensemble d'instants temporels, justement ceux dans lesquels la variable est vraie. w donne l'expression formelle de l'idée du monde.

Nous définissons aussi la notion d'assignation (S) de la façon habituelle:

S: VT --> T.

Nous appelerons CVT l'ensemble "$CT \cup VT$". Soit $t \in$ CVT.

- $VAL(t) = M_1(t)$, si $t \in$ CT.

- $VAL(t) = S(t)$, si $t \in$ VT.

Satisfaction

Soient une structure U et une assignation S.

S satisfait une ebf ϕ dans U ($U,S \models \phi$) si et seulement si:

- Si $\phi = p^t$, alors $U,S \models \phi$ si et seulement si $VAL(t) \in w(p)$.

- Si $\phi = (t_i \equiv t_j)$, alors $U,S \models \phi$ si et seulement si $VAL(t_i) = VAL(t_j)$.

- Si $\phi = (t_i \leq t_j)$, alors $U,S \models \phi$ si et seulement si $VAL(t_i) \leq VAL(t_j)$.

- Si $\phi = \neg \alpha$, alors $\mathfrak{U},S \models \phi$ si et seulement si on n'a pas $U,S \models \alpha$.

- Si $\phi = \alpha \rightarrow \beta$, alors $\mathfrak{U},S \models \phi$ si et seulement si on n'a pas $U,S \models \alpha$ ou on a $\mathfrak{U},S \models \beta$.

- Si $\phi = \forall\ vt_i.\alpha$, alors $U,S \models \phi$ si et seulement si on a $U,S' \models \alpha$, pour toute assignation S' qui est différente de S seulement dans la valeur assignée à la variable vt_i.

Vérité

Une ebf ϕ est vraie dans U (U $\models \phi$.) si et seulement si pour toute assignation S on a U,S $\models \phi$.

Validité

Une ebf ϕ est valide ($\models \phi$) si et seulement si pour toute U, ϕ est vraie dans U.

2.1 Logique de la croyance

Syntaxe

Nous présentons une logique de la croyance sur la logique temporelle que nous avons montré. Pour faire ceci nous ajoutons à l'alphabet les symboles suivants:

AG = { $a_1, a_2 \dots a_p$}. AG est un ensemble fini et non vide de symboles d'agent.

BE = { B_a^t }, pour tout $a \in$ AG et $t \in$ CVT. BE est un ensemble d'opérateurs de croyance infini, parce que les ensembles de constantes et des variables temporelles sont aussi infinis.

Ensemble d'expressions bien formées

Nous ajoutons une nouvelle règle:

(4') Si a est une ebf et $B_a^t \in$ BE, alors B_a^t a est une ebf.

Il y a une seule nouveauté entre la logique ici proposée et la logique classique de la croyance. Cette nouveauté est dans les paramètres d'agent et temporels que nous adóssons aux modalités de croyance.

Il est possible aussi de quantifier sur les agents, mais, par simplicité, nous ne le ferons pas. De même nous pensons que il nést pas réelement nécessaire, parce que normalement il y a, comme dans notre cas, un nombre fini d'agents.

...nantique

...ous définissons une structure de Kripke de la façon suivante:

UK $=_{def}$ < T, $\leq$, =, ag, W, M_1, M_2, { CR^t_a, pour tout a$\in$ ag et t$\in$T},V >, où:

- W est un ensemble non vide, dont les éléments sont appelés mondes possibles.
- V: W->F; F= {f; f:VP -> 2^T}
- ag est un ensemble fini et non vide d'agents.
- M_2: AG -> ag. M_2 est une application bijective.
- { CR^t_a, pour tout a$\in$ ag y t$\in$T} est un ensemble de relations binaires d'accessibilité: $CR^t_a \subseteq W^2$.

Satisfaction

Soient UK une structure de Kripke, w$\in$W et S une assignation, nous disons que S satisfait une ebf ϕ dans w pour UK(UK,w,S $\models \phi$) si et seulement si:

- Si $\phi = p^t$, alors UK,w,S $\models \phi$ si et seulement si VAL(t) $\in$ V(w)(p).
- Si $\phi = (t_i \equiv t_j)$, alors UK,w,S $\models \phi$ si et seulement si VAL(t_i) = VAL(t_j).
- Si $\phi = (t_i \leq t_j)$, alors UK,w,S $\models \phi$ si et seulement si VAL(t_i) $\leq$ VAL(t_j).
- Si $\phi = \neg\, \alpha$, alors UK,w,S $\models \phi$ si et seulement si on n'a pas UK,w,S $\models$ α.
- Si $\phi = \alpha \rightarrow \beta$, alors UK,w,S $\models \phi$ si et seulement si on n'a pas UK,w,S $\models \alpha$ ou on a UK,w,S $\models \beta$.
- Si $\phi = \forall\, vt_i\, \alpha$, alors UK,w,S $\models \phi$ si et seulement si on a UK,w,S' $\models$ α, pour toute assignation S' qui est différente de S seulement dans la valeur assignée à la variable vt_i.
- Si $\phi = B^t_a \alpha$, alors UK,w,S $\models \phi$ si et seulement si pour tout w' tel que <w,w'>$\in$ $CR_a^{VAL(t)}$ on a UK,w',S $\models \alpha$.

Le concept de satisfaction est défini de la façon habituelle. Nous disons qu'une ebf α est satisfaisable dans UK si et seulement s'il existe un monde w et une assignation S tels que: UK,w,S $\models \alpha$.

Une ebf α est vraie dans un monde w pour UK (UK,w $\models \alpha$) si et seulement si elle est satisfaisable pour toute assignation S. Une ebf α est UK-valide (UK $\models \alpha$) si et seulement si sa négation n'est pas satisfaisable dans UK.

Soit CU une classe de structures de Kripke. Une ebf est CU-valide si elle est UK-valide pour toute UK de CU.

Nous présentons ensuite le système KD45, mais en ajoutant les paramètres temporels. Ce système est correct pour la classe de structures avec relations d'accessibilité transitives, euclidéenes et sériales.

<u>Ensemble d'axiomes.</u>

TAU Toute instance tautologique des ebf-s de la logique propositionnelle.

B1 $\vdash B_a^t(\alpha \rightarrow \beta) \rightarrow (B_a^t \alpha \rightarrow B_a^t \beta)$ (K).

B2 $\vdash B_a^t \alpha \rightarrow \neg B_a^t \neg \alpha$ (D).

B3 $\vdash B_a^t \alpha \rightarrow B_a^t B_a^t \alpha$ (4).

B4 $\vdash \neg B_a^t \alpha \rightarrow B_a^t \neg B_a^t \alpha$ (5).

<u>Règles d'inférence.</u>

MP- Modus Ponens.

RB1- Si $\vdash \alpha$ alors $\vdash B_a^t \alpha$, pour tout t et a.

REMARQUE:

On suppose aussi que nous avons toute la logique du premier ordre, mais nous ne faisons pas mention explicite de cela.

Etant donnée la possibilité d'interactions entre les agents, nous permettons l'existence de croyances conjointes pour tous les agents. Pour ceci nous introduisons l'opérateur E^t:

$$E^t\phi \equiv_{def} B_{a_1}^t \phi \wedge \ldots\ldots\ldots\ldots \wedge B_{a_p}^t \phi .$$

Pour les croyances communes nous introduisons intuitivement l'opérateur C^t:

$$C^t\phi \equiv_{def} E^t\phi \wedge E^tE^t\phi \wedge E^tE^tE^t\phi \wedge \ldots\ldots\ldots$$

Notre langage finitaire nous oblige à l'introduire formalement dans le langage en tant qu'opérateur primitif.

La sémantique de ces deux opérateurs est la suivante:

Soient UK une structure de Kripke, s une assignation et w un monde.

- UK,w,S $\models E^t\phi$ si et seulement si , pour tout w' tel que

$\langle w,w'\rangle \in CR_{a_1}^{VAL(t)} \cup \ldots \cup CR_{a_p}^{VAL(t)}$, on a UK,w',S $\models \phi$.

- UK,w,S $\models C^t\phi$ si et seulement si , pour tout w' tel qu'il existe $<w_0,\ldots\ldots w_n>$, avec $w_0=w$, $w_n=w'$ et pour tout w_i (i=1,...,n-1) il existe k tel que $<w_i, w_{i+1}> \in CR_{a_k}^{VAL(t)}$, on a UK,w',S $\models \phi$.

Pour délimiter dans le calcul formel ces idées sémantiques on doit ajouter les axiomes suivants à notre système:

B5 $\vdash C^t\phi \rightarrow E^tC^t\phi$
B6 $\vdash (C^t\phi \wedge C^t(\phi \rightarrow \gamma)) \rightarrow C^t\gamma$
B7 $\vdash C^t(\phi \rightarrow E^t\phi) \rightarrow (E^t\phi \rightarrow C^t\phi)$.
B8 $\vdash C^t\phi \rightarrow E^t\phi$
De méme une nouvelle règle d'inférence:
RB2. Si $\vdash \phi$, alors $\vdash C^t\phi$, pour tout t.

2.2 Logique de l'intention

Nous voulons caractériser la notion d'intention. Nous l'insérons aussi sur la logique du temps d'une façon similaire à celle que nous avons vu pour la logique de la croyance, avec des nouveaux opérateurs modaux I^t_a. Nous définissons d'une maniere analogue la syntaxe et la sémantique de la logique de l'intention, mais dans ce cas nous considérons dans la sémantique des relations d'accessibilité seulement sériales (S-structures), et dans la axiomatique les axiomes K et D pour l'intention, c'est à dire:

I1 $\vdash I^t_a(\alpha\rightarrow\beta) \rightarrow (I^t_a\,\alpha \rightarrow I^t_a\,\beta)$ (K).
I2 $\vdash I^t_a\alpha \rightarrow \neg I^t_a\neg\,\alpha$ (D).

LOGIQUE DE LA CROYANCE ET DE L'INTENTION

Nous considérons maintenant une logique qui combine les logiques de la croyance et de l'intention. Le langage que nous avons défini permet seulement d'avoir des ebf-s où les opérateurs d'intention et de croyance se combinent d'une manière booléenne.

L'axiome spécifique de cette logique, qui établit (en suivant les ideés de Bratman) la consistance entre l'intention et la croyance d'un agent dans un instant concret, est le suivant:

cic: $I^t_a\phi \rightarrow \neg B^t_a\neg\phi$.

(gera91) fait une présentation analogue, mais le cadre est different en ce qui concerne le traitement du temps.

Comme propriété sémantique pour cette consistance nous proposons une propriété d'intersection (I): pour tout w (monde possible),a et t, existe un monde w': $<w,w'> \in CR^t_a$ et $<w,w'> \in IN^t_a$.

REMARQUES

(1) Le problème des effets collatéraux trouve une solution dans ce système.

(2) Nous pensons que dans un traitement modal des attitudes propositionnelles il n'est pas possible de trouver une solution au problème de la conjonction de l'intention: $I^t_a(\phi\wedge\alpha) \not\equiv (I^t_a\phi\wedge I^t_a\alpha)$ (kon91)

(3) Les deux formules que nous appelons formule de Shoham et formule de Cohen-Levesque ne sont pas valides dans la sémantique déterminée par les ETS-I-S-structures:

$I^t_a\phi \rightarrow B^t_a\phi$ (formule de Shoham. (sho90)).

$B^t_a\phi \rightarrow I^t_a\phi$ (formule de Cohen-Levesque. (cole87), (cole90)).

Nous pensons que ces deux formules n'entrent pas dans le cadre proposé par Bratman.

(4) Il est possible dans ce cadre modal de caractériser d'autres attitudes propositionnelles comme l'objectif et le désir. Une meilleure caractérisation de ces deux concepts en philosophie et en science cognitive fera possible une formalisation plus adéquate de ces deux notions.

(5) A partir de la définition des notions de croyance conjointe et commune dans ce cadre temporel, nous pouvons penser dans la notion d'intention conjointe et commune, qui sont fort intéressantes lorsqu'on veut traiter les notions d'action conjointe, commune, sociale, etc (cln90), (wer88), (wer89). Nous présentons une première idée, très basique. Nous considérons seulement deux agents et nous introduisons la notion d'intention conjointe: $IC^t_{a,b}\phi$. Ceci veut dire que a et b ont l'intention conjointe de faire ϕ. Il y a une différence avec la croyance conjointe, parce que nous ne pouvons pas définir l'intention conjointe à partir des intentions individuelles. On a:

(i) $IC^t_{a,b}\phi \rightarrow I^t_a\phi \wedge I^t_b\phi$.

mais:

(ii) $I^t_a\phi \wedge I^t_b\phi. \not\rightarrow IC^t_{a,b}\phi$

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Causation and Interference
A Working Draft

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Singular Causal Sentences: the received view

People often want causal explanations for occurrences and states of affairs. After a car accident we want to know what its causes were, and this for several purposes. We want to avoid similar accidents in the future: once we know that the baldness of the car's tyres was among the causes, we know what can be done to prevent a repeat. And we want to assign responsibility, praise or blame: once we know the car's owner was responsible for the tyres, we know whose insurance will have to pay.

Not all such explanations and attributions of responsibility are delivered in explicitly causal language. Among the other expressions which can be used for such purposes are verbs like *to cure* and *to open*; to cure some one is to cause him to become well [1]; and to open something is to cause it to become open. It is easy to think up more examples: to kill, to weaken, to excite, and so on. Such "causative" verbs make causation — and a few concepts clustered around it, like responsiblity, action, change, and agenthood — of interest in lexical semantics.

The baldness of tyres caused the accident seems to relate a particular state of affairs, the baldness of the tyres, to the accident, which is a particular occurrence, or event; other examples seem to express causal relations between two events: *the driver's attempt to brake caused the accident.* Donald Davidson called sentences like the second of these "singular causal statements" and he had an attractively simple view about what they mean. Letting C and E be two types of events, his view was essentially this: *a C caused an E* is true just in case salient particular events c and e of types C and E have occurred; and, furthermore, c was a cause of e. *The C caused the E* means, on his view, that the one and only event of type C was a cause of the one and only event of type E.

Davidson requires a causal relation between particular events. Such relations have a long history in Philosophy, and have invariably been taken to be in need of analysis. But here too a simple and appealing suggestion has been made. John Stuart Mill, following David Hume, took a

[1] Together with something else which it is difficult to say anything precise about, but which does not matter much here. Hans Kamp put to me the case of a patient who gets so angry about being given up for dead that he completely regains his will to live and, against all odds, pulls through. In a case like this it seems that being given up for dead caused the patient to regain his health. But it somehow odd to say that it cured him.

counterfactual view of causation according to which one event was a cause of another if the second would not have occurred had the first not occurred. He wrote in the *System of Logic* [2] "if a person eats of a particular dish, and dies in consequence, that is, would not have died if he had not eaten of it, people would be apt to say that eating of that dish was the cause of his death". Counterfactuals like this one were long considered suspect by Empiricist philosophers of science, but became more respectable towards the end of the 1960's with the development of modal conditional logic, by David Lewis, Robert Stalnaker and Richmond Thomason. Later Lewis took the Hume-Mill view on causation, and in his article "Causation" analysed the causal relation betweeen particular events like this: in the case of particular events *c* and *e* which have occurred (that is, they are actual events), *e* "depends causally" on *c* just in case *e* would not have occurred had *c* not occurred. And an actual event *c* is a cause of an actual event *e* if there is a chain of actual events, each causally dependent on its predecessor, of which the first is *c* and the last *e*.

Davidson's analysis of the meaning of singular causal sentences in terms of a causal relation between particular events, together with Lewis' analysis of this relation in turn in terms of counterfactuals, has been extremely influential. So influential that I will call it the "received view" on the meaning of causal statements about particular events. A great deal can be said for this view, and these authors have said much of it very clearly, working through linguistic evidence and intuitions about what was the cause of what in concrete examples. Still there are some cases which I think have been insufficiently explained, and which have led me to have doubts about both parts of the recieved view: I doubt that singular causal statements express facts about which particular events stand in the relation cause to which others. And I doubt that this relation can be fully analysed into counterfactuals about particular events.

In this note I will first give some examples which I think need better explanations. And then I will informally outline a suggestion of my own about the meaning of singular causal statements. My suggestion shares enough with the received view to explain why it seems plausible; in particular, it too enables causal claims to support counterfactuals of the kind which Hume, Mill and Lewis had in mind. But it differs from the received view in ways which, to my mind, make its treatment of these examples superior.

To begin with, here are the examples.

Three Problems for the Received View

Going to church on foot is a special way going to church; getting up late is a special way of getting up. Adverbials like "by foot" and "late" take event types and turn them into new, more restrictive types: to go to church on foot is to go to church, and to do it on foot; to go to bed late is to go to bed, and to do so at a time which, as bedtimes go, is late.

Together with Davidson's view of the logical form of singular causal sentences, this has a consequence. Suppose the one and only event of type *C* which actually occurred was *A*, so that the one and only *C* was at the same time the one and only *AC* which occurred. Similarly, suppose that the one and only *E* which actually occurred was *B*, so that it was the one and only *BE*. Then if the *AC* caused the *BE*, and if this means what Davidson says it does, then the *C* caused the *E*.

Given this much, the following example requires an explanation from Davidson.

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[2]Book III

Example 1: Last night I went to bed just once, and it was late. This morning I appeared at work, also just once, and late. In fact my late retreat last night was a cause of my late appearance this morning.

a Question: Did my late retreat last night cause my appearance at work?
my Answer: No.

On Davidson's view, of course, my appearance at work *was* caused by late retreat the previous evening. For my appearance at work was just the late appearance which, I said, was caused by this late retreat. Similarly, on his view, my going to bed caused my late appearance at work, and it caused my appearance at work.

Here are two more examples. I think they create difficulties for Lewis' counterfactual account of causal relations between particular events. They seem to show that his account is too weak — that it makes it too easy for one event to be counted among the causes of another.

Example 2: Dinosaurs, some believe, died out because the earth collided with a shower of meteorites. Now we are watching a particular dinosaur, which stops for a few minutes to drink. Meanwhile it is hit by a meteorite which drops out of the sky, and dies just after. Had the dinosaur not stopped, the meteorite would have landed harmlessly somewhere behind it.

Q. Was the dinosaur's stopping to drink a cause of its death?
A. No.

Some people — I suspect people who have been much exposed to the received view — disagree with me about whether the stopping to drink was among the causes of the death. So here is essentially the same example once again; you can see whether in this form you find it more convincing. Among the causes of the skid were the rain; the driver's stepping on the brakes; the child who walked out onto the road as the car approached, whom the driver had swerved to avoid. But the traffic light's turning red an hour beforehand didn't cause the skid. It is true that the driver would have passed a little earlier had it not turned red. And the child would in that case not have stepped out in front of him, but behind him instead. There would have been no sudden stepping on the brakes, and there would have been no skid. Still I don't think the traffic light's turning was a cause the skid.

According to Lewis, both the stopping to drink and the turning of the light were causes: the worlds most like that described but where the dinosaur didn't stop to drink are worlds where it continued unhurt. And the worlds where the traffic light did not turn red are worlds where the car continued without the skid.

Here is a last example which, like the previous one, I suppose to show that Lewis' counterfactual analysis of causation admits too many causes. This time, the spurious causes concerned are what have been called "epiphenomena". An epiphenomenon occurs before the effect but is not its cause; instead, it is itself a second effect of a third event which is the cause.

Example 3: Imagine four dominos which to begin with are arranged like this:

before

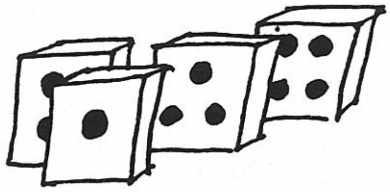

figure 1

So if the domino with one dot (call it "1") is pushed over it will in turn topple 2 and 3. And if 3 is pushed over it will in turn push over 4.

Suppose 1 is pushed over. A moment later all of the dominos have fallen:

after

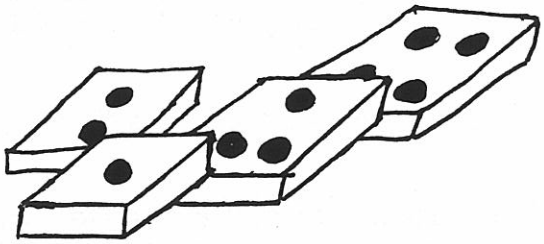

figure 2

Q. Did 2's falling cause 4 to fall?
A. No.

2's falling over did not cause 4 to fall; instead these two events were different effects of a common cause: 1's fall. Other than with example 2, I believe that holders of Lewis' view will agree with my intuitive judgement in this case; certainly Lewis did, in his discussion of epiphenomena in "Causation". His reaction there was to say that the counterfactuals involved in causal statements are of a special "nonbacktracking" sort.

To see why, evaluate the counterfactual, 4 wouldn't have fallen over if 2 hadn't (which Lewis wants to be false). Which are the possible worlds most like the real one, but where 2 didn't fall over? On the face of it these could be of two kinds: they could be worlds where 1 fell over as it actually did, but failed to take 2 with it. Or they could be worlds where 1 didn't fall in the first place and where 2, not having been hit by 1, also stayed put. In this case presumably 3 wasn't hit either, and nor was 4; presumably both of these stayed put as well.

Lewis says that worlds of the first kind are among the worlds most like the actual world, but where 2 didn't fall over: among these, then, are worlds where 1 (and 3, and 4) fell over but 2 didn't. Then the counterfactual, 4 wouldn't have fallen over if 2 hadn't, is not true, and 4's falling is not causally dependent on 2's falling. (I think he says that *all* of the worlds most like the actual world but where 2 doesn't fall are of the first kind. But in order to keep the counterfactual from being true it is sufficient that some of them are of this kind.)

According to Lewis, then, a similarity relation suitable for evaluating the counterfactuals of causal statements is of a rather special kind. It does not backtrack. It leaves the world of evaluation as it was right up until the time at which the putative cause occurs, telling us how things would continue thereafter, but without this event. In this particular case it is not too difficult to imagine such worlds in which everything except 2 falls over; I think of them as being worlds where something intervened, supporting 2 while letting the others fall.

But it is not too easy to imagine them either. What was it that intervened? Suppose there was nothing around which might have. Are nonbacktracking conditionals to be evaluated by looking at worlds in which an intervener suddenly materializes, just in time to keep the epiphenomenon from happening? Or worlds in which the epiphenomenon for some other reason fails to occur after the cause? Either way, these possibilities seem remote from the actual world. In other cases I find the possibilities nonbacktracking counterfactuals even more remote; these are cases in which it seems to me that, barring miracles, things just *couldn't* be as they were up until the epiphenomenon happened, but then continue without it. Here is an example:

Suppose that taking a dose of morphine reliably causes the pupils of the eyes to contract. (I don't know whether this is true; just suppose for the purpose of the example that this is a fact of physiology.) Now some one who has a headache takes a dose of morphine suffient to cure it. Immediately his pupils contract, and shortly afterwards the headache disappears.

> *Q.* Did the contraction cause the headache to disappear?
> *A.* No.

This example is essentially the same as the previous one: the contraction and the disappearance of the headache are two causally unrelated effects of a common cause, the taking of morphine. But this time there is, after this cause has occurred, no way of interfering to keep the effect in question from occurring. Short of a miracle there is, once morphine has been administered, a contraction. In this case the nonbacktracking counterfactual seems to introduce into the analysis of this example some possibilities which really belong to science fiction: the possibility of a miraculous interference with the nervous system, or of a physiology very different from our actual one, or of an extremely improbable failure of the morphine to have its normal effect, or something like that. It seems to me that in judging the contraction of the pupils not to have contributed to the cure, we shouldn't have to take into account possibilities like these.

I now go on to sketch an alternative view of singular causal sentences, which does not face the same difficulties as the received view (though it surely faces others). On this view, when we claim that the *C* was a cause of the *E*, we claim among other things what might be called a causal law: that making a *C* happen is a way of making an *E* happen. If this is so, then we can convince ourselves that 2's falling over was not a cause of 4's falling over, and that the contraction of the patient's pupils was not a cause of the headache's dissappearance, without taking into account the remote possibilities which Lewis needs to keep epiphenomena from being counted as causes. We only have to satisfy ourselves that making 2 fall over is not a way of making 4 fall over, and that making pupils contract is not a way of making headaches dissappear. Simple experiments will be enough to convince us of these things: we push over 2 a couple of times and watch to see if 4 follows; we make pupils contract (say by turning up the lights) and see if headaches then dissappear.

Another View

Let me quickly make my suggestion. Roughly it is this: *a C caused an E* entails at least two things. First, that there was a *C*, and later an *E*. And second, that bringing about a *C* is a way of bringing about an *E*. *The C caused the E* entails in addition that just a single *C* occurred, and just a single *E*. Notice that if I am right, singular causal statments like the ones in the above examples are misleading: they seem to just state relations between particular things, the events of which they say that the one caused the other. In fact, in entailing that one type of event is a way of bringing about another, they have lawlike consequences.

You want to know what it is for a *C* to be a way of bringing about an *E*. One thing which it does not mean is that events of the one type are *regularly* followed by those of the other. That as a matter of actual fact events of type *C* are, or have until now regularly been, followed by events of type *E*, is no reason to think that a *C* is a way of bringing about an *E*. To borrow an example from C.D. Broad: every day a factory hooter in Manchester blows at noon, and exactly at noon the workers in a factory in Leeds lay down their tools for an hour. The regularity is perfect. But blowing the hooter in Manchester is not a way of bringing it about that workers in Leeds lay down their tools for an hour. You can convince yourself of this by hooting and watching to see what happens in Leeds. (Hooting in Manchester at noon isn't a way of bringing this about either, though somebody with no idea whatsover of what is really going on might have more difficulty finding this out.)

Conversely, events of type *C* can bring about events of type *E* without being regularly followed by them. Imagine a production procedure, say for some microelectronic device, which involves growing crystals to demanding specifications: each time this process is carried out, a single crystal is the result. And suppose this procedure is tricky: only occasionally does a crystal of the required quality develop. Now under these circumstances it is I think true that carrying out the production procedure is a way of bringing it about that crystals of the required kind develop — maybe not a very good way, but still a way of bringing them into existence. However crystals of the required quality do not *regularly* develop when the production procedure is followed. They develop only in a lucky minority of cases. They may develop *more* regularly when the production process is carried out than they do spontaneously, when it is not carried out, but that is a different thing.

So now let me say what I think *bringing about* is. I know I will be replacing one concept which is not well understood with some others which are no better understood, but I think that does not matter too much. For the meantime, just tying together a number of more or less poorly understood things will already count as progress. As a first pass, then, I think that if one kind of thing is a way of bringing about another, then two things must hold: (i) in the normal course of events the second kind of thing would not happen; but (ii) if the first kind of thing does happen ("as a result of interference") then the second kind of thing can happen too, in what is thereafter the normal course of events.

Can occur. For *C* to be a way of bringing about an *E* it is not necessary that an *E* invariably occurs, if things develop normally after the occurrance of a *C*. The production procedure for quality crystals is an example here, since after the procedure is carried out it is quite normal for a crystal of the required quality to develop, even though this cannot be relied upon to happen. Where an *E* normally does ensue (think of pupils contracting after morphine is taken) we could say that *C* is an *effective* way of bringing about *E*.

This talk of what can happen "in the normal course of events" must be qualified in one way which is important in understanding causation. What normally occurs can depend very much on the context we have in mind. For this reason, whether some occurrance in conjunction with some others counts as an interference — whatever else it might be, an interference is at any rate something which does *not* occur in the normal run of things — depends too on the context. Here is an example which sometimes comes up. I think it nicely illustrates the dependence of interference, and of causation, on the context in which the events in question are placed.

There are some inflammable gases around. A spark jumps. There is also oxygen present, and following the spark an explosion occurs. Now what caused the explosion: the presence of the inflammable gases? The spark? The presence of oxygen? Some combination of these things? It seems to depend greatly on where all of this takes place. If in a room of a factory which is supposed to be free of oxygen (since inflammable gases are kept there, and there are sometimes sparks) then it seems right to point to the presence of oxygen as the cause. In a living room, where there is normally oxygen and occasionally sparks, but where there are supposed to be no inflammable gases, the presence of these (say, from a leaking pipeline) will be singled out.

This suggests that whether things of type *C* bring about things of type *E* depends in a radical way on the context. We can suppose the physical course of events involved in an explosion in the factory — the chemical reactions involved in the explosion — to be exactly the same as those in the living room; still in the one context the one factor is the cause, in the other, the other. In the factory it is the presence of oxygen which caused the explosion; the presence of inflammable gases is not the cause, since they are normally to be found there. In the living room, where there is normally oxygen but not inflammable gas, it is just the other way around.

In the rest of this note I will ignore this context sensitivity as much as I can, since this makes my talk about what is normally the case a lot less cluttered. However, it also makes some of it puzzling or untrue; at a few points I will need to introduce context anyway. With the qualification that normality is really a highly context sensitive notion, the picture I have in mind is this: if things of type *C* bring about things of type *E* then the following two conditions obtain. Firstly, in the normal course of events no *E* occurs. And, secondly, if there is a *C* then it can in the normal course of events be followed by an *E*.

For the sake of simplicity, suppose that these two conditions are all that must obtain if *C* is to be a way of bringing about *E*. And now back to the three problems which, I said, are faced by the received view. Working through them informally will give an idea of how my suggestion differs from that of Davidson and Lewis.

Three Solutions on the Suggested View

In example 1 I saw a difficulty for Davidson's view of singular causal statements: I went to bed late last night and arrived late at work. And the one was the cause of the other. I think that if Davidson is right then my going to bed late last night caused my arrival at work. And that, I think, is unintuitive.

Here is how I suggest the example be analysed. It will turn out that while going to bed late is a way of bringing about a *late* appearance at work, it is not a way of bringing about a simple appearance. For this reason, given that I have gone to bed late and have appeared late, it can be true that my going to bed late caused my late appearance, without being true that it caused my appearance.

Why is going to bed late a way of bringing about a late appearance at work? There are two conditions to check. First, it is not normally so that there is a late appearance. Let's just assume my habits to be such that this is so. (If they were otherwise then I doubt that the sentence in question would be true. At any rate I think it would be fair to counter my claim that it was going to bed late which caused my late appearance with, No — it is nothing out of the ordinary for you to turn up late like that.) As for the second condition, if I go to bed late then this can in the normal course of events be followed by a late appearance at work. This, too, sounds right.

Why is going to bed late not a way of bringing about an appearance at work, though it is a way of bringing about a late one? The difference is in the first condition: it is not so that I normally appear late at work. But I do normally appear, at some time or other.

To summarize then, given that the one and only E which has occured was the one and only F which has occurred, Davidson has to say that the C caused the E if, and only if, the C caused the F. But I am free to say that the C caused the E but not the F. I can say this if, as in this case, bringing about a C is a way of bringing about an E, but is not a way of bringing about an F.

In example 2 I saw a difficulty for Lewis' account of the causal relation between event particulars. I suppose everybody would agree that being hit by the meteorite was a cause of the dinosaur's death, and on Lewis' analysis it was, too: the meteorite hit the dinosaur, which then died, and woudn't have died if it hadn't been hit. But I think it less plausible that the dinosaur's death was causally dependent on its stopping to drink, which according to Lewis it was: the dinosaur stopped, and it died, and if it hadn't stopped then it wouldn't have died, since in that case the meteorite would have landed behind the dinosaur and brought it no harm.

There is a difference between being hit by a meteorite and stopping to drink which, on the view I am suggesting, can make the one but not the other a cause of the dinosaur's death. A direct hit by a meteorite is surely something which, in the normal course of events, is followed by a death. It may be misleading to say that a direct hit by a meteorite is "a way of bringing about" a death; this suggests that you or I could kill a dinosaur by arranging for it to be hit by a meteorite whereas, of course, we can command neither meteorites nor dinosaurs. Still, in the sense I am trying to get at a meteorite hit can be said to bring about a death. The first condition is satisfied: in the normal course of events the dinosaur does not die.[3] And the second condition is satisfied too: after being hit by a meteorite, a death can occur in the normal course of events. In fact it surely would occur in the normal course of events.

With stopping to drink it is different. This is not a way of bringing about a death, neither intuitively nor according to the criteria I have suggested. Here the first condition is satisfied just as it was above: in the normal course of events there is no death. But the second condition is not satisfied. It is not so that if a dinosaur stops to drink, then a death can occur in what is thereafter the normal course of events. A death, whether by meteor or not, is no less out of the ordinary for having been preceded by a drink. In the normal course of events, after a drink just as before, there is no death.

Finally, in example 3 I saw another problem for Lewis's account of causation: accept it and you are committed to nonbacktracking counterfactuals; accept these and you bring into the discussion possibilites which, to my mind, shouldn't be needed in order to explain why domino 2's falling over

[3] The dinosaur must die sometime of course, and it is normal for it to die sometime. But if we were describing a normal day in the life of this dinosaur, it surely would not involve a death. Here we see some of the context dependence of the notion of a normal course of events which, oversimplifying, I have left out of the discussion here: relative to something global like the animal's expected life span, a death is a normal thing; it must happen at some time or other. But on the more local timescale of a day in the dinosaur'ts life, a death is not a normal occurrence.

is not among the causes of 4's falling over. I also suggested how this example could be analysed without bringing these possibilities into things. What needs to be shown, on my view of the meaning of singular causal sentences, is that 2's falling over is not a way of bringing it about that 4 falls.

Now 2's falling over would be a way of bringing it about that 4 falls if the two conditions were to hold. I argue that while the first one does, the second does not. The first condition is that in the normal course of events 4 does not fall over. With the set-up as I described it, in which the four domino stones are lined up in the configuration of *figure 1*, it seems indeed that provided things are left alone, none of the dominos will topple. Thinking of the normal course of events in this way, as what will happen provided there is no intereference, it seems that relative to this set up it is indeed so that in the normal course of events 4 will not fall over.

The second condition is that if 2 falls over, then in what is thereafter the normal couse of events 4 can fall over too. And this, I argue, is not so: there are cases in which 2 falls over, but where it is not so that 4 can fall in what is thereafter the normal course of events. The cases I am thinking of are ones where 2 is toppled (say, we interfere by pushing this domino stone over) but where none of the others are interfered with. In such cases, it seems to me, the normal course of events thereafter — that is, without any further intereference after that which is required to topple 2 — excludes the possibility of 4's falling. I conclude that 2's falling over is not a way of bringing it about that 4 falls, and that therefore the fall by 2 which actually occurred is not among the causes of the fall by 4 which actually occurred.

Will it be Possible to be more Precise about Normal Courses of Events?

In this note I have tried to bring out some of the relations between causation, bringing about events, and the notion of normal courses of events. Whether sense can be made of what I have said depends very much on whether sense can be made of this latter notion. Here, apart from hinting at the relationship between this notion and lack of interference, I have said nothing about how the notion of a normal course of events can be understood. David Lewis' counterfactual account, by contrast, is backed up by his impressive account of counterfactuals in possible-worlds theory; this counts in its favour.

For the moment I have wanted to postpone formal work to underpin these notions. The informal work of working through examples has been hard enough, and it must be well under way before trying to become more formal. I am afraid it would be easy to waste a lot of time working on concept of bringing about, or the concept of a normal course of events, only to find that the results are not much help in understanding causation.

Still it will be necessary to go into concepts in more depth at some stage, so it is better at least to have some idea of which way this work will go. Here I can indicate the general direction.

I plan to formalize the notion of a normal course of events by borrowing from two areas which have already developed quite far separately, but which have not yet met. The one is the modal logic of branching time; in fact the idea of looking at branching temporal structures in analysing causation is an old one, it goes back to von Wright. Temporal histories will be my courses of events. The other area will contribute the concept of normality: the field of "nonmonotonic reasoning" which has sprung up in Artificial Intelligence circles has studied normality, and how people reason with it. Most of this work is rather conservative as regards the logical languages used, and originally did not venture outside of the setting of classical first-order logic. More recent work inspired by modal conditional logic promises to dovetail better with temporal logic, however. It is this work which I intend to apply in studying nornmal courses of events and the part they play in causation.

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LE RAISONNEMENT CARTESIEN
UN RAISONNEMENT NON MONOTONE POUR UN DIALOGUE COOPERATIF HOMME_MACHINE

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"Les actions de la vie ne souffrant souvent aucun délai, c'est une vérité très certaine que, lorsqu'il n'est pas en notre pouvoir de discerner les plus vraies opinions, nous devons suivre les plus probables; et même qu'encore que nous ne remarquions point d'avantage de probabilité aux unes qu'aux autres, nous devons néanmoins nous déterminer à quelques unes, et les considérer après, non plus comme douteuses en tant qu'elles se rapportent à la pratique, mais très vraies et très certaines, à cause que la raison qui nous y a fait déterminer se trouve telle." DESCARTES Discours de la Méthode

Dans cet article nous présentons un formalisme pour un raisonnement non-monotone, le Raisonnement Cartésien.

Aux paragraphes 1 et 2. Nous en donnons le cadre général et les principales définitions du versant syntaxique.

Au paragraphe 3, nous exposons quelques problèmes relatifs à la coopérativité d'une réponse machine posée par un humain. En réponse à ces problèmes nous définissons la notion de HUCHINE.

Au paragraphe 4, nous définissons une théorie de la preuve pour le raisonnement cartésien et en donnons quelques propriétés.

Au paragraphe 5, nous comparons le raisonnement cartésien à la logique des défauts de Reiter sur des exemples d'écoles.

Enfin au paragraphe 6, nous définissons pour le raisonnement cartésien une sémantique proche de la théorie des modèles, et nous montrons, par le théorème 6.8, l'adéquation de la théorie de la déduction à cette sémantique, nous l'illustrons ensuite sur l'exemple 6.9.

1. Introduction

Lorsque nous raisonnons, nous ne faisons pas uniquement des déductions à partir d'observations et de lois qui nous sont connues pour être vraies. Afin que l'incertitude ne nous mène pas à l'indécision, n'étant pas omniscients, nous devons faire des hypothèses sur le monde. Si nous ne le faisions pas notre capacité de raisonnement serait extrêmement réduite, et raisonner ne nous serait presque toujours d'aucune aide pour prendre les décisions les plus quotidiennes. Par exemple, si lorsque nous avons égaré nos clefs nous cherchons à nous rappeler où nous les avons posées pour la dernière fois, c'est en effet que nous avons fait l'hypothèse que " *des clefs restent à l'endroit où on les a posées* ". Cette loi ne nous est pourtant pas connue pour être vraie, mais nous l'adoptons provisoirement comme vraie afin de pouvoir ensuite déduire où elles sont. Si, par aventure, elles ne sont pas là où nous les avions laissées, alors nous réviserons notre Raisonnement, et la loi qui dit que " *des clefs restent à l'endroit où on les a posées* " sera abandonnée, car sinon notre théorie n'aurait pas pour modèle " Le monde réel ". C'est ainsi que nous sommes amenés à raisonner de manière non monotone.

La non monotonie est un problème de Raisonnement; Comment utiliser la Logique dans le raisonnement qui n'est pas uniquement déductif. La Logique nous servant uniquement à prédire ce qui serait " VRAI" dans le monde, si le monde était un modèle de telle ou telle théorie. Raisonner c'est construire une théorie puis, grâce à la Logique, calculer à partir de cette théorie ce qui est " VRAI " dans un modèle de cette théorie. Si ces prédictions ne sont pas en accord avec nos observations sur le "monde réel" (c'est à dire qu'elles ne sont pas valides dans notre modèle) nous révisons alors cette théorie. Les prédictions ainsi obtenues ne sont que des vérités virtuelles. Ceci vient du fait que pour construire une théorie suffisament informative sur le monde, nous sommes amenés à adopter des hypothèses comme des règles vraies, alors que la valeur de vérité de ces règles est contingente à la conjoncture. Aussi, nous appelerons ces règles des Règles Contingentes par opposition aux Règles effectives qui elles, sont toujours vraies.

2. Présomptions et Formules Présumables

Nous nous placerons dans le cadre général de la Logique classique, le calcul des prédicats [PAB 76 [GOC 90], [END 72], [KLE 71], [BLA 70], [TAR 72]. Nous supposons qu'il nous est donné un langage du premier ordre construit sur un alphabet dénombrable. Par formule, nous entendrons formule bien formée de ce langage.

2.1. Exemple *"en général un oiseau vole"*

Supposons que nous sachions que *titi est un oiseau*. Et que, par l'expérience que nous avons du monde, nous sachions que *en général un oiseau vole*. Nous pouvons considérer le fait que titi est un oiseau comme une Règle Effective, car nous pouvons utiliser cette règle à tout moment, elle n'est pas Contingente. Ce que l'on peut noter par :

Effectif oiseau(titi)

Le fait qu'un oiseau vole est par contre une Règle Contingente, car ceci dépend de l'oiseau considéré (Si c'est un pingouin alors il ne vole pas.) Ce que l'on peut noter par:

Contingent oiseau(X) → vole(X) : {¬pingouin(X) }

Ce qui exprime que pour un individu b nous ne pouvons utiliser la règle oiseau(b)→vole(b) que sous le précepte suivant : Nous ne pouvons pas prouver que b est un pingouin. Une autre manière de le dire est que la réunion de l'ensemble des Règles Effectives et de {¬pingouin(b)} est un ensemble consistant. Nous dirons que {¬pingouin(X)} est un ensemble Précepte de la Règle Contingente oiseau(X)→vole(X)

Nous supposons que nous disposons des ensembles $\mathcal{E}$ et $\mathcal{H}$ tels que :

i $\mathcal{E}$ est un ensemble de formules closes que nous traiterons comme **Règles Effectives**. Nous supposons que $\mathcal{E}$, l'ensemble des Règles Effectives, est consistant. Ces règles nous sont connues pour être vraies.

ii $\mathcal{H}$ est l'ensemble des **Hypothèses supposables**. C'est un ensemble de couples (R , P) où R est une formule, et P un ensemble fini de formules. R sera appelé une **Règle Contingente**, et P un **Précepte de** cette Règle Contingente.

($\mathcal{E}$,$\mathcal{H}$) est appelé une théorie Cartésienne.

Toutes instances sans variable de règles contingentes peuvent être utilisées lors d'une démonstration si une réunion de leurs Préceptes est consistante avec $\mathcal{E}$. Pour une formule donnée, nous cherchons un ensemble de Règles Contingentes qui, avec $\mathcal{E}$ l'ensemble des Règles Effectives impliquent la formule telles qu'une réunion de leur Préceptes et de $\mathcal{E}$ soit consistante.

2.2. Définition Préceptes Associés et aprioris

Soit (R,P) une hypothèse, où R est donc une Règle Contingente, P={P_1, . . . ,P_n} son Précepte. Soit θ une substitution. Alors { $\forall P_1\theta, \ldots, \forall P_n\theta$ } est un **Précepte Associé** à Rθ.

Soit C un ensemble d'instances de règles contingentes et A une réunion de préceptes associés à chaque élément de C. Alors A est appelé un **apriori** de C.

2.3. Exemple Préceptes associés et Aprioris

Supposons que en général " *un ami d'un ami soit un ami. (Sauf s'il est ennemi d'un ami,)* ". Ce que l'on peut noter comme Règle Contingente :

Contingent ami(X,Z) ∧ ami(Z,Y) → ami(X,Y) : {¬(ami(X,T) ∧ ennemi(Y,T)) }

Soit ami(léo,louis) ∧ ami(louis,luc)→ami(léo,luc) l'instance sans variable de la règle contingente ami(X,Z) ∧ ami(Z,Y)→ami(X,Y). Alors le Précepte Associé à :

ami(léo,louis) ∧ ami(louis,luc)→ami(léo,luc) est {∀T(¬(ami(leo,T)∧ennemi(luc,T))}

2.4. Remarque Règles contingentes et leurs préceptes

Une règle contingente n'a pas nécessairement un seul précepte associé.

Si nous avons par exemple : H_1 **Contingent** b : {a,¬c} H_2 **Contingent** b : {a,¬d}

H_3 **Contingent** c : {c}

La règle contingente b qui apparait dans H_1 et H_2 a ici deux préceptes associés qui sont : {a,¬c} et {a,¬d

Aussi {b,c} qui est un ensemble d'instances de règles contingentes, a deux aprioris qui sont {a,˥c,c} et {a,˥d,c}

2.5. Définition Présomptions

Une **Présomption de ($\mathcal{E}$,$\mathcal{H}$)** est un ensemble $\mathcal{E} \cup$ C où C est un ensemble d'instances sans variable de Règles Contingentes, tel qu'il existe un apriori A de C, tel que $\mathcal{E} \cup$ A soit consistant.

2.6. Définition Formules affirmables, présumables et justifications

Si f est une formule close, C un ensemble d'instances sans variable de Règles Contingentes, A un apriori de C tel que $\mathcal{E} \cup$ A soit consistant, c'est à dire que $\mathcal{E} \cup$ C est une Présomption de ($\mathcal{E}$,$\mathcal{H}$), alors nous dirons que **f est une formule Présumable pour ($\mathcal{E}$,$\mathcal{H}$), et que A est une Justification de f pour ($\mathcal{E}$,$\mathcal{H}$)** si $\mathcal{E} \cup C \vdash f$.

f est une formule Affirmable pour ($\mathcal{E}$,$\mathcal{H}$), si $\mathcal{E} \vdash f$. (où $\vdash$ est l'inférence classique).

Ce qui veut dire que f est une formule Présumable pour ($\mathcal{E}$,$\mathcal{H}$), et que A en est une Justification pour ($\mathcal{E}$,$\mathcal{H}$) si il existe C un ensemble d'instances sans variable de Règles Contingentes dont A est un apriori tel que: i $\mathcal{E} \cup C \vdash f$ ii $\mathcal{E} \cup A \nvdash \bot$

Mais ceci ne nous garantit pas que $\mathcal{E} \cup$ C soit consistant.

2.7. Exemple Lulu l'autruche vole

Supposons, comme dans l'exemple 2.1, que par l'expérience que nous avons du monde nous sachions que:

en général un oiseau vole (sauf si c'est un pingouin).

et que nous sachions aussi que:

une autruche est un oiseau
une autruche ne vole pas
lulu est une autruche
titi est un oiseau

Ce que l'on peut traduire par:

(1) **Effectif** ∀X (autruche(X) → oiseau(X))
(2) **Effectif** ∀X (autruche(X) → ˥ vole(X))
(3) **Effectif** autruche(lulu)
(4) **Effectif** oiseau(titi)
(5) **Contingent** oiseau(X) → vole(X) : {˥pingouin(X) }

Dans ce cas grace aux Règles Effectives (2) et (3) nous pouvons déduire ˥vole(lulu). Nous avons pu le déduire sans faire appel aux Hypothèses supposables. Nous en sommes donc certains. Dans ce cas sa Justification est Ø. Une telle formule est affirmable. Mais nous pouvons aussi dire que vole(lulu) est présumable et que { ˥pingouin(lulu) } en est une Justification car: (1) De la réunion des Règles Effectives et de l'instance sans variable de la Règle Contingente oiseau(lulu)→vole(lulu) dont le Précepte associé est { ˥pingouin(lulu) } nous pouvons déduire vole(lulu) c'est à dire que
$\mathcal{E} \cup$ {oiseau(lulu)→vole(lulu)} $\vdash$ vole(lulu) et nous avons aussi que:
(2) {∀X(autruche(X)→oiseau(X)), ∀X(autruche(X)→˥vole(X)), autruche(lulu), oiseau(titi)} ∪ {˥pingouin(lulu)} $\nvdash \bot$. C'est à dire que $\mathcal{E} \cup$ { ˥pingouin(lulu) } est consistant.

Or ceci est contre-intuitif. Si nous sommes certains de la véracité d'une formule, nous ne devrions pas pouvoir présumer de sa négation. Et c'est pourtant le cas dans l'exemple ci-dessus puisque ˥vole(lulu) y est une formule affirmable, et que vole(lulu) peut y être calculé comme formule présumable avec pour Justification { ˥pingouin(lulu) }. Ceci vient du fait que dans la définition 2.6 d'une formule présumable f nous demandons que: i $\mathcal{E} \cup C \vdash f$ ii $\mathcal{E} \cup A \nvdash \bot$ (par la définition 2.5)
mais pas que $\mathcal{E} \cup C \nvdash \bot$. D'ailleurs dans l'exemple précédent $\mathcal{E} \cup$ C n'est pas consistant. Pour éviter cela nous pourions changer la définition 2.6 d'une formule présumable en exigeant que:

i' $\mathcal{E} \cup C \vdash f$ ii' $\mathcal{E} \cup A \cup C \nvdash \bot$

Ce qui résoudrait le problème car dans ce cas, si f est une formule affirmable, c'est à dire que $\mathcal{E} \vdash f$ alors

$\mathcal{E} \cup C \nvdash \neg f$. En effet si $\mathcal{E} \vdash f$ alors $\mathcal{E} \cup C \vdash f$ et $\mathcal{E} \cup C \cup A$ étant consistant, $\mathcal{E} \cup C$ l'est aussi, donc $\mathcal{E} \cup C \nvdash \neg f$. Mais comme nous allons le voir, si nous choisissons cette voie la Justification de f qui est A ne serait pas une Justification Coopérative de f.

3. Des Justifications Coopératives

Afin de résoudre le problème soulevé ci-dessus nous allons imposer des contraintes aux préceptes des Règles Contingentes, et ainsi obtenir en plus la coopérativité d'une Justification d'un but présumable.

Reprenons l'exemple 2.1 :

Effectif oiseau(titi) **Contingent** oiseau(X) → vole(X) : {¬pingouin(X) }

Si nous voulions respecter la règle de qualité du principe de coopérativité de Grice [GRI75]:

Qualité "Que votre contribution soit véridique"

et ses deux règles plus spécifiques :

Qualité (a) " N'affirmez pas ce que vous croyez être faux"

Qualité (b) " N'affirmez pas ce pour quoi vous manquez de preuves"

Alors, à la question vole(titi), la réponse ne devrait pas être "OUI", car répondre "OUI" c'est violer la règle (b) puisque nous n'avons pas la preuve que titi n'est pas un pingouin. Répondre "OUI" n'est donc pas coopératif (au sens de Grice). Mais quelqu'un qui interpréterait la coopérativité de cette manière serait vite accusé de ne pas être "coopératif".

Donnons un autre exemple de cette utilisation trop stricte de la règle de qualité. Imaginons que Lucile veuille emprunter la voiture de Léo et qu'à la question " *où est ta voiture?* " la réponse de Léo est " *Je ne sais pas* " (bien qu'il se souvienne très bien où l'avoir garée). Léo répond " *Je ne sais pas* " sous le prétexte que la régle " *Une voiture reste là où on l'a garée* " est une Règle contingente car elle n'est vraie que en général (par exemple elle est fausse si la voiture a été volée, ou enlevée pour la fourrière) donc qu'il ne peut utiliser cette Règle qui est une Règle Contingente s'il veut respecter la règle de qualité (b) du Principe de Coopérativité :

Qualité (b) "N'affirmez pas ce pour quoi vous manquez de preuves".

Dans un tel cas il semble légitime que Lucile reproche le manque de "coopérativité" de Léo. A moins, comme le suggère Grice dans "Logic and conversation" pour un exemple semblable, que Lucile interprète la réponse de Léo comme une dérision ("flouting") de la première règle de quantité du Principe de Coopérativité (CP) :

Quantité (a) "Que votre contribution contienne autant d'informations qu'il est requis (pour les visées conjoncturelles de l'échange)".

Car Léo a la possibilité d'en dire plus; Par ailleurs il n'ignore pas que Lucile lui demande plus d'informations que cela. Il faut donc que Léo soit supposé vouloir transmettre une information qu'il répugne à exprimer. Cette supposition ne tient que si Lucile présume qu'il ne veut pas prêter sa voiture, et ce serait donc cela que Léo implicite.

Léo aurait pu répondre :

(1) *"Au coin de la rue, (si la voiture est restée là où je l'ai garée, et je peux le supposer car je n'ai, ni la preuve qu'on me l'aie volée, ni qu'elle ai été enlevée pour la fourrière) ".*

Bien sûr cette réponse nous semble ridicule, mais quand Léo répond "*Au coin de la rue*" Lucile entend bien la premiére réponse (1) car elle sait que Léo respecte la deuxième règle de Quantité du CP :

Quantité (b) "Que votre contribution ne contienne pas plus d'informations qu'il n'est requis"

Et la partie entre parenthèses de la réponse (1) n'est pas requise car Lucile sait que Léo a dû faire cette hypothèse pour lui répondre, et que Léo sait que Lucile le sait.

On peut dire que la partie entre parenthèses de la réponse (1) en est la **Justification Coopérative**, attirant l'attention de l'auditeur sur le fait que l'on ai dû adopter pour vraies certaines Hypothèses dont on n'est pas certain, mais qu'il est légitime de supposer vraies puisque nous savons que, en général elles sont vérifiées, et qu'elles sont actuellement consistantes avec ce dont on est certain (Les Règles Effectives).

Nous pouvons en général nous passer de la Justification Coopérative d'une réponse en vertu de l'application de la deuxième règle de Quantité du CP. Car l'être Humain a, avec son interlocuteur humain, une expérience en commun du monde, il le sait, et il sait que son interlocuteur le sait. Cette expérience commune amène les deux interlocuteurs humains à posséder en commun une connaissance sur le monde, ainsi que sur leurs connaissances réciproques, notamment sur les hypothèses que l'expèrience du monde qu'il partagent les amène à formuler.

Il n'est pas possible de se passer de la Justification Coopérative d'une réponse si c'est une machine qui nous répond. En effet, nous avons besoin de savoir si une réponse est affirmable oubien seulement présumable. Or si la machine répond seulement " OUI ", Lucile ne connaissant pas le contexte de calcul de cette machine (les règles que la machine possède), elle ne peut pas savoir, comme pour Léo si la réponse est affirmable ou bien seulement présumable. Et si nous imposons à une machine de ne donner uniquement les réponses affirmables, nous avons vu qu'elle ne nous serait pas d'une grande aide. Sauf peut-être pour effectuer de longues déductions rapidement. Mais ce serait alors prendre la machine comme " machine à calculer ", alors que nous cherchons à construire des " machines à raisonner ".

Une machine ne serait pas coopérative si elle imitait le comportement humain. Car lorsque nous nous adressons à une machine, nous savons parfaitement que ce n'est pas un être humain. En général, nous ne possédons aucune information sur le contexte de calcul d'une machine (les règles qu'elle possède), et la machine ne connait pas ce que nous connaissons sur son contexte.

Le principe de coopérativité de Grice concerne la communication Humain-Humain. Pour la communication Humain-Machine, nous pourions développer un autre principe de coopérativité en adaptant les maximes de Grice de la communication Humain-Humain, afin d'obtrenir de nouvelles maximes pour la communication Humain-Machine. Mais c'est le pôle Humain de la communication Humain-Machine que nous voulons privilégier (afin de mettre la machine à la porté de l'homme et non l'homme à la porté de la machine). Et c'est pour cette raison que nous retiendrons le principe de coopérativité de Grice. Simplement, nous considèrerons que l'un de ces Humains (la Machine) est un Humain particulier, que nous appelerons un **HUCHINE**.

- Un HUCHINE respecte le principe de coopérativité de Grice.
- Mais un HUCHINE sait que son interlocuteur HUMAIN n'a aucune connaissance sur les règles et les hypothèses qu'est susceptible d'adopter un HUCHINE.

Accompagner une réponse de sa justification coopérative semble donc un bon compromis coopératif entre le " OUI " qui manque de Qualité, et le " JENESAIS PAS " qui manque de Quantité pour un tel HUCHINE.

Reprenons maintenant l'exemple 2.1 : **effectif** oiseau(titi)

Contingent oiseau(X) → vole(X) : {┐pingouin(X) }

Si nous posons la question : - ? vole(titi) et que la réponse est : 'OUI' / [┐pingouin(titi)]

Ce qui exprime : " OUI titi vole (*car je peux faire l'hypothèse que titi n'est pas un pingouin*) ".

Alors la justification de la réponse ne respecte pas la première règle de Quantité du CP.

Quantité (a) "Que votre contribution contienne autant d'informations qu'il est requis (pour les visées conjoncturelles de l'échange)".

En effet il manque l'information que l'on doit aussi faire l'hypothèse que : oiseau(titi) → vole(titi) pour pouvoir répondre "OUI".

Aussi pour éviter cette carence des Justifications, afin de les rendre réellement Coopératives, nous imposerons à une Règle Contingente d'appartenir à son précepte.

3.1. Exemple Lulu l'autruche ne vole plus

l'exemple 2.7 devient alors :

(1)	**Effectif**	$\forall X$(autruche(X) → oiseau(X))
(2)	**Effectif**	$\forall X$(autruche(X) → ┐vole(X))
(3)	**Effectif**	autruche(lulu)
(4)	**Effectif**	oiseau(titi)
(5)	**Contingent**	oiseau(X) → vole(X) : {oiseau(X) → vole(X), ┐pingouin(X) }

ici vole(titi) est une formule présumable pour ($\mathcal{E}$,$\mathcal{H}$) et maintenant sa Justification est : [oiseau(titi) → vole(titi), ┐pingouin(titi)]. Car :

(1) $\mathcal{E} \cup$ {oiseau(titi) → vole(titi) } $\vdash$ vole(titi)

(2) $\mathcal{E} \cup$ {oiseau(titi) → vole(titi), ┐pingouin(titi) } $\nvdash \perp$

$\neg$ vole(lulu) reste une formule affirmable pour $(\mathcal{E},\mathcal{H})$, car $\mathcal{E} \vdash \neg$ vole(lulu); Mais vole(lulu) n'est plu une formule présumable car si l'on a encore :

(1) $\mathcal{E} \cup \{$oiseau(lulu) $\rightarrow$ vole(lulu) $\} \vdash$ vole(lulu)

nous n'avons plus que :

(2) $\mathcal{E} \cup \{$oiseau(lulu) $\rightarrow$ vole(lulu), $\neg$ pingouin(lulu) $\} \nvdash \perp$

Par le théorème qui suit nous allons voir qu'en gardant les définitions 2.2, 2.5, 2.6 mais en imposant à ur règle contingente d'appartenir à son précepte le problème qu'une formule soit présumable bien que : négation soit affirmable est supprimé.

Mais auparavant rappellons ces définitions :

i Une théorie Cartésienne $(\mathcal{E},\mathcal{H})$ est déterminée par la donnée des deux ensembles $\mathcal{E}$ et $\mathcal{H}$ tel que :

i-1 $\mathcal{E}$ est un ensemble de formules closes. Nous supposons que $\mathcal{E}$ est consistant.

i-2 $\mathcal{H}$ est un ensemble de couples (R,P) où R est une formule, et P un ensemble fini c formules tel que R$\in$P. R est appelé une **Règle Contingente** , et P un **Précepte** de cette Règ Contingente.

ii Soit H=(R,P) une hypothèse, où R est donc une Règle Contingente, P=$\{R,P_1, \ldots, P_n\}$ so Précepte par H Soit θ une substitution. Alors $\{\forall R\theta, \forall P_1\theta, \ldots, \forall P_n\theta\}$ est un **Précepte Associé** à Rθ.

Soit C un ensemble d'instances de règles contingentes et A une réunion de préceptes associés à chaqu élément de C. Alors A est appelé un **apriori** de C.

iii Une **Présomption de $(\mathcal{E},\mathcal{H})$** est un ensemble $\mathcal{E} \cup$ C où C est un ensemble d'instances sans variable c Règle Contingentes, tel qu'il existe un apriori A de C, tel que $\mathcal{E} \cup$ A soit consistant.

iv Si f est une formule close, C un ensemble d'instances sans variables de Règles Contingentes, A u apriori de C tel que $\mathcal{E} \cup$ A soit consistant, c'est à dire que $\mathcal{E} \cup$ C est une Présomption de $(\mathcal{E},\mathcal{H})$, alors nou dirons que **f est une formule Présumable pour $(\mathcal{E},\mathcal{H})$, et que A est une Justification de f pour $(\mathcal{E},\mathcal{H})$** $\mathcal{E} \cup C \vdash f$.

f est une formule Affirmable pour $(\mathcal{E},\mathcal{H})$, si $\mathcal{E} \vdash$ f. (où $\vdash$ est l'inférence classique).

3.2. Théorème

Si f est une formule affirmable pour $(\mathcal{E},\mathcal{H})$, alors $\neg$f n'est pas présumable pour $(\mathcal{E},\mathcal{H})$.

Démonstration : □□□ Si f est une formule affirmable pour $(\mathcal{E},\mathcal{H})$, alors : (1) $\mathcal{E} \vdash f$

Supposons que $\neg$f soit une formule présumable pour $(\mathcal{E},\mathcal{H})$. Alors il existe C un ensemble d'instanc sans variables de règles contingentes et A un apriori de C tels que: (2) $\mathcal{E} \cup C \vdash \neg f$ (3) $\mathcal{E} \cup \nvdash \perp$

Or puisque toute règle contingente appartient à son précepte, il est clair que C$\subseteq$A, mais alors d'après (2) $\cup$ A $\vdash \neg$f, mais d'après (1) $\mathcal{E} \cup$ A $\vdash$ f, ce qui contredit (3). Donc $\neg$f n'est pas une formule présumable pou $(\mathcal{E},\mathcal{H})$. ■

3.3. Théorème

Si f est une formule présumable pour $(\mathcal{E},\mathcal{H})$, alors il existe une Justification coopérative finie de f pou $(\mathcal{E},\mathcal{H})$.

Démonstration : □□□ Rappelons que pour tout ensemble de formules fini ou dénombrable Σ, si $\Sigma \vdash$ alors il existe un ensemble fini Σ' / $\Sigma' \subseteq \Sigma$ et $\Sigma' \vdash$ f (car la déduction est fini). Le théorème ci-dessus e une conséquence immédiate de cette remarque et du fait que les préceptes sont des ensembles finis c formules. ■

4. Le Raisonnement Cartésien et ses Conjectures

4.1. Définition Conjectures

Une Conjecture de $(\mathcal{E},\mathcal{H})$ est l'ensemble des théorèmes d'une présomption maximale de $(\mathcal{E},\mathcal{H}$ (maximale au sens de l'inclusion ensembliste)

4.2. Théorème

Soit $(\mathcal{E},\mathcal{H})$ une théorie cartésienne telle que $\mathcal{H}$ est fini. Alors pour toute présomption $\mathcal{E}\cup C$ de $(\mathcal{E},\mathcal{H})$ il existe une présomption maximale $\mathcal{E}\cup\mathcal{M}$ de $(\mathcal{E},\mathcal{H})$ telle que $(\mathcal{E}\cup C)\subseteq(\mathcal{E}\cup\mathcal{M})$.

Démonstration:□□□ Soit $\mathcal{P}_C$ l'ensemble des présomptions contenant $\mathcal{E}\cup C$. C'est à dire :

$\mathcal{P}_C = \{\mathcal{E}\cup X / \mathcal{E}\cup X$ est une présomption de $(\mathcal{E},\mathcal{H})$ et $C\subseteq X\}$

Montrons que $\mathcal{P}_C$ est un ensemble inductif pour $\subseteq$. (On appelle inductif un ensemble ordonné dans lequel tout sous-ensemble totalement ordonné [ou chaîne] admet un majorant.)

Soit donc B une chaîne de $\mathcal{P}_C$; Montrons qu'elle admet un majorant.

Si B est fini: alors B peut se mettre sous la forme $\{\mathcal{E}\cup X_0, \mathcal{E}\cup X_1, \ldots, \mathcal{E}\cup X_n\}$ où (IN étant l'ensemble des Entiers Naturels) pour tout $i\in IN$ et $j\in IN$ tel que $0\leq i\leq n$ et $0\leq j\leq n$, si $i<j$ alors $X_i\subset X_j$; car B est une chaîne de $\mathcal{P}_C$. Il est alors clair que $\mathcal{E}\cup X_n$ est un majorant de B et que $(\mathcal{E}\cup X_n)\in\mathcal{P}_C$.

Si B est infini: alors B est dénombrable, donc B peut se mettre sous la forme $\{\mathcal{E}\cup X_0, \mathcal{E}\cup X_1, \ldots, \mathcal{E}\cup X_i, \ldots\}$ où pour tout $i\in IN$ et $j\in IN$ si $i<j$ alors $X_i\subset X_j$; car B est une chaine infinie de $\mathcal{P}_C$.

posons $M = \bigcup_{(\mathcal{E}\cup X)\in B} X = \bigcup_{i\in IN} X_i$ qui est donc un ensemble d'instances sans variables de règles contingentes. Il est clair que M est infini dénombrable.

Montrons que $\mathcal{E}\cup M$ est un majorant de B. Nous aurons donc montré que $\mathcal{P}_C$ est inductif.

i Pour tout élément de B, $(\mathcal{E}\cup Y)$, il est clair que $(\mathcal{E}\cup Y)\subseteq(\mathcal{E}\cup M)=\mathcal{E}\cup(\bigcup_{(\mathcal{E}\cup X)\in B} X)$.

ii Montrons que $(\mathcal{E}\cup M)\in\mathcal{P}_C$.

ii-1 Pour tout élément de B, $(\mathcal{E}\cup Y)$, il est clair que $C\subseteq Y$ car $B\subseteq\mathcal{P}_C$, par la suite $C\subseteq M = \bigcup_{(\mathcal{E}\cup X)\in B} X$.

ii-2 Montrons que $\mathcal{E}\cup M$ est une présomption de $(\mathcal{E},\mathcal{H})$.

Nous devons donc montrer qu'il existe A un apriori de M tel que $\mathcal{E}\cup A\not\vdash\bot$.

- Puisque M est infini dénombrable alors il est clair qu'il existe $h: IN\rightarrow M$ qui est une bijection.
- Posons $P_i = \{P /$ tel que P est un précepte associé à $h(i)\}$. L'ensemble des hypothèses étant fini, il est clair que pour tout $i\in IN$, P_i est fini.
- Pour tout $i\in IN$, $\mathcal{E}\cup X_i$ étant une présomption de $(\mathcal{E},\mathcal{H})$ il existe R_i un apriori de X_i / $\mathcal{E}\cup R_i\not\vdash\bot$, où R_i est donc une réunion de préceptes associés à chaque élément de X_i. Soit Q_i l'ensemble de ces préceptes. Nous avons donc que $R_i = \bigcup_{X\in Q_i} X$.

Soit donc $Q_0, Q_1, \ldots, Q_i, \ldots$ une suite telle que pour tout $i\in IN$, $\bigcup_{X\in Q_i} X$ est un apriori de X_i tel que $\mathcal{E}\cup(\bigcup_{X\in Q_i} X)\not\vdash\bot$.

Soit $(A_0,N_0), (A_1,N_1), \ldots, (A_i,N_i), \ldots$ la suite construite comme suit:

i=0 : Puisque $h(0)\in M=\bigcup_{i\in IN} X_i$ alors il existe $k\in IN$ / $h(0)\in X_k$. Mais puisque $X_0, X_1, \ldots X_i, \ldots$ est une chaîne alors pour tout $j\in IN$ tel que $k\leq j$, $h(0)\in X_j$. Pour chaque Q_j / $k\leq j$ il existe donc $P\in P_0$ tel que $P\in Q_j$ car $\bigcup_{X\in Q_j} X$ est un apriori de X_j et $h(0)\in X_j$. Mais $\{X\in IN / k\leq X\}$ étant infini et P_0 étant fini, il est clair qu'il existe au moins un $P\in P_0$ tel que pour tout $j\in IN$ et $k\leq j$ il existe $i\in IN$ / $j<i$ tel que $P\in Q_i$. Notons A_0 un tel P. Posons $N_0=\{i\in IN / A_0\in Q_i\}$. Il est clair que N_0 est infini dénombrable.

$i\in IN$: Supposons que N_{i-1} est un ensemble infini dénombrable qui est inclus dans IN.

Puisque $h(i)\in M=\bigcup_{i\in IN} X_i$ alors il existe $k\in IN$ / $h(i)\in X_k$. Mais puisque $X_0, X_1, \ldots X_i, \ldots$ est une chaîne alors pour tout $j\in IN$ tel que $k\leq j$, $h(i)\in X_j$. Donc il existe $k'\in N_{i-1}$ tel que pour tout $j\in N_{i-1}$ tel que $k'\leq j$, $h(i)\in X_j$. Pour

chaque Q_j tel que $j\in N_{i-1}$ et $k'\leq j$ il existe donc $P\in P_i$ tel que $P\in Q_j$ car $\bigcup_{X\in Q_j} X$ est un apriori de X_j et $h(i)\in X_j$
Mais $\{X\in N_{i-1}/k'\leq X\}$ étant infini et P_i étant fini, il est clair qu'il existe au moins un $P\in P_i$ tel que pour tout $j\in N_{i-1}$ et $k'\leq j$ il existe $g\in N_{i-1}/j\leq g$ tel que $P\in Q_g$. Notons A_i un tel P. Posons $N_i=\{g\in N_{i-1}/A_i\in Q_g\}$. Il est clair que N_i est infini dénombrable.
N_0 étant infini dénombrable, et puisque si N_{i-1} est infini dénombrable alors N_i est infini dénombrable il est clair que pour tout $i\in \mathbb{N}$, N_i est infini dénombrable. Notre suite est donc bien définie.

Posons $A=\bigcup_{i\in \mathbb{N}} A_i$. Par construction il est clair que A est un apriori de M

Montrons que $\mathcal{E}\cup A \nvdash \perp$.

Pour cela montrons que toute partie finie de $\mathcal{E}\cup A$ est consistante. En effet un tel ensemble fini peut se mettre sous la forme $F\cup G$ où $F\subseteq \mathcal{E}$, et $G\subseteq A=\bigcup_{i\in \mathbb{N}} A_i$ et F ainsi que G sont finis.

Puisque G est fini et que $G\subseteq \bigcup_{i\in \mathbb{N}} A_i$ il est clair qu'il existe $k\in \mathbb{N}$ tel que $G\subseteq \bigcup_{i\leq k} A_i$. Or par construction des (A_i,N_i) il est clair que pour tout $g\in N_k$, $(\bigcup_{i\leq k} A_i)\subseteq \bigcup_{X\in Q_g} X$. Or pour tout $i\in \mathbb{N}$, $\mathcal{E}\cup(\bigcup_{X\in Q_i} X)\nvdash \perp$ donc $\mathcal{E}\cup(\bigcup_{i\leq k} A_i)\nvdash \perp$, et par la suite $\mathcal{E}\cup G\nvdash \perp$. Donc $F\cup G\nvdash \perp$.

Puis par la complétude de la déduction tout sous-ensemble fini de $\mathcal{E}\cup A$ a un modèle. Mais alors par le théorème de compacité qui dit que:
"<u>Soit Σ un ensemble dénombrable de formules. Si toute partie finie de Σ a un modèle alors Σ a un modèle.</u>"
nous pouvons dire que $\mathcal{E}\cup A$ a un modèle. Puis par la justesse de la déduction que $\mathcal{E}\cup A\nvdash \perp$.

Nous avons donc montré qu'il existe A un apriori de M tel que $\mathcal{E}\cup A\nvdash \perp$. Mais alors $\mathcal{E}\cup M$ est une présomption de $(\mathcal{E},\mathcal{H})$.

Par **ii-1** nous avons montré que $C\subseteq M$

Par **ii-2** nous avons montré que $\mathcal{E}\cup M$ est une présomption de $(\mathcal{E},\mathcal{H})$.

Donc par **ii-1** et **ii-2** nous avons montré **ii** c'est à dire que $(\mathcal{E}\cup M)\in \mathcal{P}_C$.

Par **i** nous avons montré que pour tout élément de B, $(\mathcal{E}\cup Y)$, $(\mathcal{E}\cup Y)\subseteq(\mathcal{E}\cup M)$

Donc toute chaîne infinie de $\mathcal{P}_C$ admet un majorant.

Mais alors toute chaîne (finie ou infinie) B de $\mathcal{P}_C$ admet un majorant dans $\mathcal{P}_C$. Nous avons donc montré que $\mathcal{P}_C$ est inductif.

Mais alors grâce au théorème de Zorn qui dit que:
"<u>Tout ensemble inductif admet au moins un élément maximal.</u>"

Nous pouvons dire que $\mathcal{P}_C$ admet au moins un élément maximal.

Soit $\mathcal{E}\cup\mathcal{M}$ un élément maximal de $\mathcal{P}_C$

Il est clair que $C\subseteq\mathcal{M}$ car $(\mathcal{E}\cup\mathcal{M})\in \mathcal{P}_C$

Montrons que $\mathcal{E}\cup\mathcal{M}$ est aussi un élément maximal de l'ensemble des présomptions. Nous aurons ainsi démontré le théorème.

Il est clair que $\mathcal{E}\cup\mathcal{M}$ est une présomption.

Montrons que $\mathcal{E}\cup\mathcal{M}$ est maximale dans l'ensemble des présomptions.

Supposons que $\mathcal{E}\cup X$ est une présomption telle que $(\mathcal{E}\cup\mathcal{M})\subseteq(\mathcal{E}\cup X)$.

Alors $(\mathcal{E}\cup X)\in \mathcal{P}_C$ car $(\mathcal{E}\cup C)\subseteq(\mathcal{E}\cup\mathcal{M})\subseteq(\mathcal{E}\cup X)$.

Mais alors $(\mathcal{E}\cup\mathcal{M})$ étant maximale dans $\mathcal{P}_C$ et puisque nous avons supposé que $(\mathcal{E}\cup\mathcal{M})\subseteq(\mathcal{E}\cup X)$ nous avons que $(\mathcal{E}\cup X)=(\mathcal{E}\cup\mathcal{M})$. Donc $\mathcal{E}\cup\mathcal{M}$ est une présomption maximale, et de plus $(\mathcal{E}\cup C)\subseteq(\mathcal{E}\cup\mathcal{M})$.

■■■

4.3. Théorème

Soit $(\mathcal{E},\mathcal{H})$ une théorie cartésienne telle que $\mathcal{H}$ est fini. Alors il existe toujours une Conjecture.

Démonstration: □□□ Puisque que nous avons imposé que $\mathcal{E}$ soit consistant, il suffit de remarquer que $\mathcal{E}\cup\emptyset$ est toujours une présomption de $(\mathcal{E},\mathcal{H})$ pour tout ensemble d'hypothèses $\mathcal{H}$. Mais alors par le théorème 4.2 il existe au moins une présomption maximale pour $(\mathcal{E},\mathcal{H})$ et donc une conjecture.

■■■

4.4. Théorème

Soit $(\mathcal{E},\mathcal{H})$ une théorie cartésienne telle que $\mathcal{H}$ est fini. Une formule f est présumable pour $(\mathcal{E},\mathcal{H})$ si et seulement si f est dans une Conjecture de $(\mathcal{E},\mathcal{H})$.

Démonstration: □□□ Si f est présumable pour $(\mathcal{E},\mathcal{H})$, alors il existe une présomption $\mathcal{E}\cup C$ pour $(\mathcal{E},\mathcal{H})$ telle que $\mathcal{E}\cup C \vdash f$. Mais d'après le théorème 4.2, il existe pour $(\mathcal{E},\mathcal{H})$ une présomption maximale $\mathcal{E}\cup M$ telle que $(\mathcal{E}\cup C)\subseteq(\mathcal{E}\cup M)$ donc $\mathcal{E}\cup M \vdash f$, donc f est un théorème de $\mathcal{E}\cup M$ qui est une présomption maximale de $(\mathcal{E},\mathcal{H})$; donc f est dans une conjecture de $(\mathcal{E},\mathcal{H})$.

Inversement : Si f est dans une conjecture de $(\mathcal{E},\mathcal{H})$, alors il existe une présomption maximale $\mathcal{E}\cup M$ pour $(\mathcal{E},\mathcal{H})$ telle que $\mathcal{E}\cup M \vdash f$, donc f est présumable pour $(\mathcal{E},\mathcal{H})$.

■■■

4.5. Théorème

Ajouter une Hypothèse ne peut que faire croître le nombre de formules présumables.

Démonstration: □□□ Soit $\mathcal{E}$ un ensemble de règles effectives et $\mathcal{H}$ un ensemble d'hypothèses.
Soit $\mathcal{H}_1$ tel que $\mathcal{H}\subset\mathcal{H}_1$.
Montrons que si f est présumable pour $(\mathcal{E},\mathcal{H})$ alors f est présumable pour $(\mathcal{E},\mathcal{H}_1)$.
En effet si f est présumable pour $(\mathcal{E},\mathcal{H})$ alors il existe une présomption $\mathcal{E}\cup C$ pour $(\mathcal{E},\mathcal{H})$ telle que $\mathcal{E}\cup C \vdash f$. Or il est clair que si $\mathcal{E}\cup C$ est une présomption pour $(\mathcal{E},\mathcal{H})$, alors $\mathcal{E}\cup C$ est aussi une présomption pour $(\mathcal{E},\mathcal{H}_1)$, car $\mathcal{H}\subset\mathcal{H}_1$. Mais alors f est présumable pour $(\mathcal{E},\mathcal{H}_1)$.

■■■

4.6. Exemple Ajouter une Hypothèse

Soit les assertions suivantes : *Léo est quacker* *Léo est républicain*
En général un quacker est pacifiste

Que l'on peut représenter par :
(1) **Effectif** quacker(léo)
(2) **Effectif** républicain(léo)
(3) **Contingent** quacker(X) → pacifiste(X) : {quacker(X) → pacifist(X)}

Ici pacifist(léo) est présumable avec pour justification coopérative [quacker(léo)→pacifist(léo)] .
Mais ¬pacifist(léo) n'est pas présumable.
Si l'on rajoute l'hypothèse :

en général un républicain n'est pas pacifiste

Que l'on peut représenter par :

(4) **Contingent** républicain(X) → ¬pacifist(X) : {républicain(X) → ¬pacifist(X)}

Maintenant ¬pacifist(léo) est présumable avec pour justification coopérative [républicain(léo)→¬pacifist(léo)].

4.7. Théorème

Ajouter une formule à un précepte d'une régle contingente ne peut que faire décroître le nombre de formules présumables.

Démonstration: □□□ Soit $\mathcal{E}$ un ensemble de règles effectives et $\mathcal{H}$ un ensemble d'hypothèses.
soit (R,P) une hypothèse possible de $\mathcal{H}$.
Soit P_1 tel que $P\subset P_1$
Soit $\mathcal{H}_1 = (\mathcal{H} - \{(R,P)\}) \cup \{(R,P_1)\}$. (On remplace (R,P) par (R,P_1))

Montrons que si f est présumable pour $(\mathcal{E},\mathcal{H}_1)$ alors f est présumable pour $(\mathcal{E},\mathcal{H})$.
Si f est présumable pour $(\mathcal{E},\mathcal{H}_1)$ alors il existe une présomption $\mathcal{E}\cup C$ pour $(\mathcal{E},\mathcal{H}_1)$ telle que $\mathcal{E}\cup C \vdash f$.
Montrons que f est aussi présumable pour $(\mathcal{E},\mathcal{H})$.
En effet

(1) Il est clair que $\mathcal{E}\cup C \vdash f$.

(2) Soit Q une réunion des préceptes associés dans $\mathcal{H}_1$ aux instances sans variable des règles contingentes de C telle que $\mathcal{E}\cup Q$ est consistant; Q existe car $\mathcal{E}\cup C$ est une présomption pour $(\mathcal{E},\mathcal{H}_1)$. Soit Q la réunion des préceptes associés dans $\mathcal{H}$ aux instances sans variable des règles contingentes de C; tel que l'on a choisi les mêmes préceptes que pour construire Q, et si $P_1 \in Q$ alors on le remplace par P dans Q. Il est clair que Q est un apriori de C dans $(\mathcal{E},\mathcal{H})$. Il est clair que $Q \subseteq Q$ donc que $\mathcal{E}\cup Q$ est aussi consistant.

Par (1) et (2) f est présumable pour $(\mathcal{E},\mathcal{H})$. $\blacksquare$

4.8. Exemple Ajouter une formule à un précepte

soit les assertions suivantes :

loulou est une autruche
les autruches sont des oiseaux
En général un oiseau vole (à moins que ce ne soit un pingouin).

Que l'on peut représenter par :

(1)	**Effectif**	autruche(loulou)
(2)	**Effectif**	$\forall X$(autruche(X) → oiseau(X))
(3)	**Contingent**	oiseau(X) → vole(X) : {oiseau(X) → vole(X), ¬pingouin(X)}

Ici vole(loulou) est présumable avec pour justification coopérative [oiseau(loulou) → vole(loulou), ¬pingouin(loulou)].
Si l'on rajoute au précepte de (3) la formule ¬autruche(X) on obtient alors

(3')	**Contingent**	oiseau(X) → vole(X) : {oiseau(X) → vole(X), ¬pingouin(X), ¬autruche(X)}

Maintenant avec les règles (1), (2) et (3') vole(loulou) n'est plus présumable.

4.9. Exemple Bloquer la contraposée d'une règle contingente

soit les assertions suivantes :

leo est un homme
louis est roi
En général un homme n'est pas roi.

Que l'on représente par :

(1)	**Effectif**	homme(léo)
(2)	**Effectif**	roi(louis)
(3)	**Contingent**	homme(X) → ¬roi(X) : {homme(X) → ¬roi(X)}

Ici la formule ¬roi(léo) est présumable, avec pour justification coopérative [homme(léo) → ¬roi(léo)] ce qui semble intuitivement correct.
Mais la formule ¬homme(louis) est aussi présumable, avec pour justification coopérative [homme(louis) → ¬roi(louis)] car on peut utiliser la contraposée de homme(louis) → ¬roi(louis) qui est roi(louis) → ¬homme(louis) ce qui n'est pas intuitif. Pour éviter cela on peut rajouter au précepte de la règle contingente (3) la formule homme(X). On obtient ainsi

(3')	**Contingent**	homme(X) → ¬roi(X) : {homme(X) → ¬roi(X), homme(X)}

Alors par les règles (1), (2) et (3') nous pouvons conclure que ¬roi(léo) est une formule présumable avec pour justification coopérative {homme(léo) → ¬roi(léo), homme(léo)}.
Mais maintenant ¬homme(louis) n'est plus présumable, en effet {homme(léo), roi(louis)} ∪ {homme(louis) → ¬roi(louis), homme(louis)} est inconsistant.

5. Le Raisonnement Cartésien et la Logique des Défauts

La logique des défauts [REI 80], [SOM 88], est une logique non-monotone qui a été introduite par Reiter pour formaliser le raisonnement par défaut. Une théorie des défauts $\Delta = (D,W)$ est composée d'un ensemble de faits W qui sont des formules closes du premier ordre et d'un ensemble de défauts D.

Un défaut est une expression de la forme : $\dfrac{a(X)\ :\ b_1(X),\ .\ .\ .\ ,b_n(X)}{w(X)}$

où $a(X)$, $b_1(X)$, . . . ,$b_n(X)$, $w(X)$ sont des formules bien formées dont les variables libres sont toutes parmi celles de $X = X_1, \ldots, X_k$.
$a(X)$ est appelé le prérequis du défaut; $b_1(X), \ldots, b_n(X)$ sa justification; et $w(X)$ le conséquent du défaut.
La signification d'une telle formule est la suivante:
Si $a(X)$ est connu et si $b_1(X) \wedge \ldots \wedge b_n(X)$ est consistant avec ce qui est connu, alors inférer $w(X)$.

Un défaut est dit normal si il est de la forme : $\dfrac{a(X)\ :\ w(X)}{w(X)}$

Un défaut est dit semi-normal si il est de la forme : $\dfrac{a(X)\ :\ b_1(X),\ .\ .\ .\ ,b_n(X),w(X)}{w(X)}$

Un défaut est clos si aucun des a, $b_1, \ldots, b_n$, w ne contient de variables libres.
Une théorie des défauts clos, est une théorie des défauts $\Delta = (D,W)$ où tous les défauts de D sont clos.

5.1. Définition Extention [REITER]

Soit $\Delta = (D,W)$ une théorie des défauts clos, c'est à dire où tous les défauts de D sont de la forme $(a : b1, \ldots, bn/w)$ où $a, b1, \ldots, bn, w$ sont des formules bien formées closes. Pour tout ensemble de formules closes S soit $\Gamma(S)$ le plus petit ensemble qui satisfait les trois propriétés suivantes :

D1 : $W \subseteq \Gamma(S)$

D2 : $Th(\Gamma(S)) = \Gamma(S)$

D3 : Si $(a : b1, \ldots, bn/w) \in D$ et $a \in \Gamma(S)$ et $\neg b1, \ldots, \neg bn \notin S$ alors $w \in S$.

Un ensemble E de formules closes est une extention pour Δ si et seulement si $\Gamma(E) = E$, c'est à dire E est un point fixe de l'opérateur Γ.

Par le théorème qui suit nous établissons un paralléle entre notre notion de conjecture pour le Raisonnement Cartésien et la notion d'extention d'une théorie des défauts clos pour la Logique des Défauts.

5.2. Théorème

Soit $(\mathcal{E},\mathcal{H})$ une théorie cartésienne telle que $\mathcal{H}$ est fini. Soit $\mathcal{C}$ une conjecture de $(\mathcal{E},\mathcal{H})$; d'après la définition 4.1, il existe M un ensemble d'instances sans variable de règles contingentes et P un apriori de M tels que :

(a) $\mathcal{E} \cup M$ est une présomption maximale de $(\mathcal{E},\mathcal{H})$; $\mathcal{E} \cup P$ est consistant.

(b) $\mathcal{C} = Th(\mathcal{E} \cup M)$

Alors :

(1') $\mathcal{E} \subseteq \mathcal{C}$

(2') $Th(\mathcal{C}) = \mathcal{C}$

(3') Si A est une instance sans variable d'une règle contingente et que l'un de ses préceptes associés Q est tel que $\mathcal{E} \cup P \cup Q$ est consistant alors $A \in \mathcal{C}$.

De plus $\mathcal{C}$ est minimale par rapport au trois propriétés ci-dessus.

Démonstration:□□□ <u>Propriété (1')</u> : Il est clair que $\mathcal{E} \subseteq \mathcal{C} = Th(\mathcal{E} \cup M)$.

<u>Propriété (2')</u> : Il est clair aussi que $Th(\mathcal{C}) = Th(Th(\mathcal{E} \cup M)) = Th(\mathcal{E} \cup M) = \mathcal{C}$.

<u>Propriété (3')</u> : Supposons que A est une instance sans variable d'une règle contingente et que l'un de ses préceptes associés Q est tel que $\mathcal{E} \cup P \cup Q$ est consistant.

Si $A \notin \mathcal{C} = Th(\mathcal{E} \cup M)$ c'est que $A \notin \mathcal{E} \cup M$, mais alors $\mathcal{E} \cup M \cup \{A\} \neq \mathcal{E} \cup M$ et $\mathcal{E} \cup M \subset \mathcal{E} \cup M \cup \{A\}$ et $\mathcal{E} \cup (M \cup \{A\})$ est une présomption pour $(\mathcal{E},\mathcal{H})$ car Q le précepte associé à A, est tel que $\mathcal{E} \cup (P \cup Q)$ est consistant. Mais alors $\mathcal{E}\cup M$ n'est pas maximale, ce qui contredit nos hypothèses. Donc $A \in \mathcal{C}$.

Montrons la minimalité de $\mathcal{C}$ par rapport aux trois propriétés.

Supposons que $\mathcal{C}'$ est un ensemble qui a les trois propriétés ci-dessus et que $\mathcal{C}' \subset \mathcal{C}$ et $\mathcal{C}' \neq \mathcal{C}$. Alors il existe B une instance sans variable de règle contingente telle que $B \in M$ et $B \notin \mathcal{C}'$. (En effet si $M \subseteq \mathcal{C}'$ on aurait $\mathcal{C}=Th(\mathcal{E}\cup M) \subseteq Th(\mathcal{E}\cup M \cup \mathcal{C}')=Th(\mathcal{C}')=\mathcal{C}'$ et ceci car $\mathcal{E} \subseteq \mathcal{C}'$ par la propriété (1'), et $Th(\mathcal{C}')=\mathcal{C}'$ par la propriété (2').)

Soit Q un précepte associé à B / $Q \subseteq P$ (il existe car $B \in M$) donc $\mathcal{E}\cup P \cup Q$ est consistant; $\mathcal{E}\cup P$ l'étant. Mais $B \notin \mathcal{C}'$ ce qui contredit la propriété (3'). Donc un tel ensemble $\mathcal{C}'$ n'existe pas, d'où $\mathcal{C}$ est minimale.

■

Les propriétés (1') et (2') du théorème 5.2 sont identiques aux propriétés D1 et D2 de la définition 5.1 d'une extention pour une théorie des défauts dos de Reiter.

La propriété (3') diffère de la propriété D3. Remarquons d'abord que la propriété (3') exige dans sa partie condition que :

"A soit une instance sans variable d'une règle contingente et que Q un précepte associé à A soit tel que $\mathcal{E}\cup P \cup Q$ soit consistant."

Mais alors $\mathcal{C}\cup Q$ est aussi consistant. En effet $\mathcal{C}=Th(\mathcal{E}\cup M)$ et $(Th(\mathcal{E}\cup M))\cup Q$ est consistant car comme nous avons imposé à une règle contingente d'appartenir à son précepte, il est clair que $M \subseteq P$ donc que $\mathcal{E}\cup M \cup Q$ est consistant donc que $(Th(\mathcal{E}\cup M))\cup Q$ est consistant et enfin que $\mathcal{C}\cup Q$ est consistant.

Q le précepte d'une règle contingente correspond à la justification d'un défaut chez Reiter. Or Reiter pour déduire une formule f à partir d'une théorie $\Delta=(D,W)$ n'exige pas que l'ensemble des justifications des défauts utilisés pour cette déduction soit consistante avec W. Alors que pour qu'une formule f soit présumable pour $(\mathcal{E},\mathcal{H})$, nous exigeons qu'il existe C un ensemble d'instances sans variables de règles contingentes dont un apriori P (une réunion de leurs préceptes associés) est tel que $\mathcal{E}\cup C \vdash f$ et $\mathcal{E}\cup P \nvdash \perp$ (que l'ensemble des 'justifications' soit consistant avec l'ensemble des faits connus W).

On peut traduire un défaut : $\dfrac{a(X)\ :\ b_1(X),\ .\ .\ .\ ,b_n(X)}{w(X)}$

en une règle contingente comme :

Contingent $a(X) \rightarrow w(X) : \{a(X) \rightarrow w(X), b_1(X),\ .\ .\ .\ , b_n(X)\}$

On peut remarquer qu'alors le défaut semi-normal sans prérequis

$$\dfrac{:a(X)\rightarrow w(X), b_1(X),\ .\ .\ .\ ,b_n(X)}{a(X)\rightarrow w(X)}$$

se traduit aussi en

Contingent $a(X) \rightarrow w(X) : \{a(X) \rightarrow w(X), b_1(X),\ .\ .\ .\ , b_n(X)\}$

Les règles contingentes forcent les défauts à être semi-normaux sans prérequis.

Cependant, par le fait que nous exigions la consistance d'un apriori (une réunion de l'ensemble de préceptes associés; justifications chez Reiter) avec l'ensemble des règles effectives (faits connus chez Reiter), ce que n'exige pas la Logique des défauts, nous n'obtenons pas les mêmes propriétés que pour les théories des défaut semi-normaux sans prérequis.

5.3. Exemple Défauts semi-normaux sans prérequis & raisonnement cartésien

Soit $\left(\left\{\dfrac{:\ a,b}{b}, \dfrac{:\ c,d}{d}\right\}, \left\{\neg a \vee \neg c\right\}\right)$ la théorie $\Delta_1=(D_1,W_1)$

que nous traduirons donc en $\{\neg a \vee \neg c\}=\mathcal{E}_1, \mathcal{H}_1=\{b:\{a,b\}, d:\{c,d\}\}$

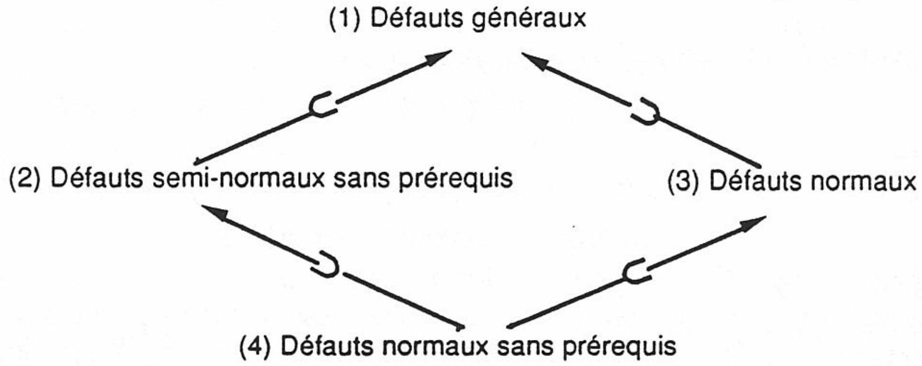
<u>Pour la Logique des défauts</u> : $Th(\{\neg a \vee \neg c, b, d\})$ est une extention pour Δ_1 et l'on peut donc déduire $b \wedge d$. Ce qui est contre intuitif car nous avons dû faire la supposition que $a \wedge b \wedge c \wedge d$ alors que $a \wedge c$ nous est connu pour être faux car nous savons que $\neg a \vee \neg c$.

Pour le Raisonnement Cartésien : b est une formule présumable pour $\mathcal{E}_1,\mathcal{H}_1$ dont [a,b] est une justification coopérative car $\{\neg a \vee \neg c\} \cup \{b\} \vdash b$ et $\{\neg a \vee \neg c\} \cup \{a,b\} \nvdash \perp$.
d est une formule présumable pour $\mathcal{E}_1,\mathcal{H}_1$ dont [c,d] est une justification coopérative car $\{\neg a \vee \neg c\} \cup \{d\} \vdash d$ et $\{\neg a \vee \neg c\} \cup \{c,d\} \nvdash \perp$.

Alors que $b \wedge d$ n'est pas une formule présumable pour $\mathcal{E}_1,\mathcal{H}_1$ car si $\{\neg a \vee \neg c\} \cup (\{b\} \cup \{d\}) \vdash b \wedge d$ par contre $\{\neg a \vee \neg c\} \cup (\{a,b\} \cup \{c,d\}) \vdash \perp$.

La différence vient du fait que si l'on peut déduire $b \wedge d$ dans la théorie Δ_1, c'est qu'on porte un regard local sur la justification de chaque défaut utilisé pour construire l'extention $Th(\{\neg a \vee \neg c, b, d\})$; Et par là que l'on ne prend pas en compte l'information que l'on a dû supposer a puis c si l'on utilise les deux défauts $\frac{:\ a,b}{b}, \frac{:\ c,d}{d}$ dans une même extention afin de déduire $b \wedge d$ bien que $\neg a \vee \neg c$ soit connu pour être vrai.
Alors que dans le raisonnement Cartésien on porte un regard global sur l'ensemble des préceptes associés de toutes les règles contingentes utilisées pour savoir si une formule est présumable. Ceci par le fait que l'on demande à ce qu'un apriori (un ensemble des préceptes associés de toutes les règles contingentes utilisées) soit consistant avec $\mathcal{E}$ l'ensemble des règles effectives (les faits connus pour être vrais).

Afin d'éviter ce problème des défauts semi-normaux sans prérequis qui peuvent avoir un comportement non intuitif on pourrait se limiter aux défauts normaux sans prérequis (voir Figure 5.4).



5.4. Figure

Mais les défauts normaux sans prérequis manque d'expressivité. Par exemple on ne peut interdire l'utilisation de la contraposée.

5.5. Exemple Défauts normaux sans prérequis & raisonnement cartésien

reprenons l'exemple 4.9 où nous avions les assertions suivantes :

leo est un homme
louis est roi
En général un homme n'est pas roi

Que l'on peut, dans le cadre d'une théorie des défauts normaux sans prérequis représenter par la théorie :

$$\Delta = (\{\frac{:\ homme(X) \rightarrow \neg roi(X)}{homme(X) \rightarrow \neg roi(X)}\}, \{homme(léo), roi(louis)\}).$$

Alors $Th(\{homme(leo) \rightarrow \neg roi(leo), homme(louis) \rightarrow \neg roi(louis), homme(léo), roi(louis)\})$ est une extention. Mais alors on peut déduire $\neg homme(louis)$ par l'utilisation de la contraposée de $homme(louis) \rightarrow \neg roi(louis)$ qui est $roi(louis) \rightarrow \neg homme(louis)$ ce qui n'est pas intuitif. Et l'on ne peut pas interdire l'utilisation de la contraposée comme nous l'avons fait dans l'exemple 4.9 si on veut rester dans le cadre d'une théorie des défauts normaux sans prérequis.

On pourrait alors vouloir utiliser les défaut normaux. On pourrait ainsi, dans le cadre d'une théorie des défauts normaux, traduire l'exemple 5.5 par la théorie :

$$\Delta' = \left(\left\{\frac{homme(X) : \neg roi(X)}{\neg roi(X)}\right\}, \{homme(léo), roi(louis)\}\right).$$

Ici dans Δ', on ne peut plus déduire $\neg homme(louis)$.

Mais les défauts normaux peuvent avoir un mauvais comportement par rapport aux information disjonctives.

5.6. Exemple défauts normaux & raisonnement cartésien

Soit les assertions suivantes :

lou est un chat ou un chien

En général un chat est apprivoisé

En général un chien est apprivoisé

Que l'on peut, dans le cadre d'une théorie des défauts normaux représenter par la théorie :

$$\Delta = \left(\left\{\frac{chat(X) : apprivoisé(X)}{apprivoisé(X)}, \frac{chien(X) : apprivoisé(X)}{apprivoisé(X)}\right\}, \{chat(lou) \vee chien(lou)\}\right).$$

Ici on ne peut pas déduire $apprivoisé(lou)$ qui n'est dans aucune extention de Δ.

Alors que si l'on représente ces assertions dans le cadre du raisonnement cartésien nous obtenons :

(1)	**Effectif**	$chat(lou) \vee chien(lou)$
(2)	**Contingent**	$chat(X) \rightarrow apprivoisé(X) : \{chat(X) \rightarrow apprivoisé(X)\}$
(3)	**Contingent**	$chien(X) \rightarrow apprivoisé(X) : \{chien(X) \rightarrow apprivoisé(X)\}$

Ici $apprivoisé(lou)$ est une formule présumable; avec pour justification coopérative $[chat(lou) \rightarrow apprivoisé(lou), chien(lou) \rightarrow apprivoisé(lou)]$

car :

$$\{chat(lou) \vee chien(lou)\} \cup \{chat(lou) \rightarrow apprivoisé(lou), chien(lou) \rightarrow apprivoisé(lou)\} \vdash apprivoisé(lou)$$

et

$$\{chat(lou) \vee chien(lou)\} \cup \{chat(lou) \rightarrow apprivoisé(lou), chien(lou) \rightarrow apprivoisé(lou)\} \nvdash \perp$$

Au regard de la figure 5.4 nous pouvons dire pour résumer.

(4) Défauts normaux sans prérequis : Manque d'expressivité; On ne peut pas bloquer la contraposée ou bien bloquer un défaut en rajoutant une formule à sa justification (ce qui le rendrait semi-normal sans prérequis). (voir exemple 5.5).

(3) Défauts normaux : Expressivité inadéquate (trop peu de formules déduites); On ne prend pas en compte l'information disjonctive, d'où, l'on ne déduit pas certaines informations. (voir exemple 5.6).

(2) Défauts semi-normaux sans prérequis : Expressivité inadéquate (trop de formule déduites); On déduit des formules que l'on ne souhaiterait pas voir déduite. Car on ne tient pas compte de l'ensemble des suppositions implicites lors d'une déduction (voir exemple 5.3).

(1) Défauts généraux : Réuni les problèmes de (2) et (3) et de plus l'existence d'une extention n'est pas assurée. Ce qui est un inconvénient majeur, car on devrait au moins pouvoir déduire ce dont on est sûr.

Quand au raisonnement Cartésien : Nous avons vu par le théorème 4.3 qu'il existe toujours une conjecture si l'ensemble des hypothèses est fini (ce qui est contraignant). Il possède les qualités de (2), c'est à dire qu'il a un pouvoir expressif correct; On peut bloquer la contraposée, ou limiter l'utilisation d'une règle contingente en rajoutant des formules à son précepte (voir exemples 4.8 & 4.9) mais pas les inconvénients de (2) ni de (3); Son expressivité est adéquate à l'intuition.

Ni trop peu : Il a un bon comportement face aux informations disjonctives (voir exemple 5.6); Car lors d'une déduction on utilise une règle contingente comme une règle effective, et c'est seulement si une déduction aboutit que l'on vérifie la consistance de la réunion de l'ensemble des préceptes associés aux règles contingentes utilisées lors de la déduction avec l'ensemble $\mathcal{E}$ des règles effectives (faits connus)

Ni trop : On ne déduit pas des formules qu'on ne souhaite pas déduire (voir exemple 5.3); Car on prend en compte l'ensemble des préceptes associés aux règles contingentes utilisées lors d'une déduction, qui doit être consistant avec l'ensemble $\mathcal{E}$ des règles effectives (faits connus).

6. Des Univers et des Modèles Cartésiens

6.1. Définition $\mathcal{I}_{\mathcal{E}}$ les modèles de $\mathcal{E}$

Soit une théorie Cartésienne $(\mathcal{E},\mathcal{H})$ de langage $\mathcal{L}$.
Soit $\mathcal{D}$ un domaine d'interprétaion de $\mathcal{L}$.

Nous noterons $\mathcal{I}_{\mathcal{E}}$ **l'ensemble des interprétations de $\mathcal{L}$ sur $\mathcal{D}$ qui sont des modèles de $\mathcal{E}$.** ($\mathcal{I}_{\mathcal{E}}$ n'est pas vide car la déduction est complète, et nous avons supposé que $\mathcal{E}$ est consistant)

6.2. définition $D_{\mathcal{H}}$, $E_{(\mathcal{E},\mathcal{H})}$ et $F_{(\mathcal{E},\mathcal{H})}$

Posons $\mathbf{D}_{\mathcal{H}}$ **={(R,P) tel que R est une instance sans variable d'une règle contingente d'une Hypothèse de $\mathcal{H}$, et P son précepte associé dans $\mathcal{H}$}**
Soit $\mathcal{P}(D_{\mathcal{H}})$ l'ensemble des parties de $D_{\mathcal{H}}$.

Posons $\mathbf{E}_{(\mathcal{E},\mathcal{H})}$ **=$\{C \in \mathcal{P}(D_{\mathcal{H}})$ tel qu'il existe une interprétation $I \in \mathcal{I}_{\mathcal{E}}$ tel que pour tout $(R,P) \in C$, P est vrai pour I$\}$.**

Posons $\mathbf{F}_{(\mathcal{E},\mathcal{H})}$ **=$\{X$ tel qu'il existe $C \in E_{(\mathcal{E},\mathcal{H})}$ tel que $X = \bigcup_{(R,P)\in C}\{R\}$** $\}$.
Il est clair que $\subseteq$ est une relation d'ordre sur $F_{(\mathcal{E},\mathcal{H})}$

6.3. Théorème

Soit $(\mathcal{E},\mathcal{H})$ une théorie cartésienne où $\mathcal{H}$ est fini. Alors $F_{(\mathcal{E},\mathcal{H})}$ a au moins un élément maximal pour $\subseteq$.

Démonstration;□□□ Montrons que $F_{(\mathcal{E},\mathcal{H})}$ est inductif. (On appelle inductif un ensemble ordonné dans lequel tout sous-ensemble totalement ordonné [ou chaîne] admet un majorant.)
Soit donc B une chaîne de $F_{(\mathcal{E},\mathcal{H})}$; Montrons qu'elle admet un majorant.

<u>Si B est fini</u>: alors B peut se mettre sous la forme $\{X_0, X_1, \ldots X_n\}$ où (IN étant l'ensemble des Entiers Naturels) pour tout $i \in IN$ et $j \in IN$ tel que $0 \le i \le n$ et $0 \le j \le n$, si $i < j$ alors $X_i \subset X_j$; car B est une chaîne de $F_{(\mathcal{E},\mathcal{H})}$. Il est alors clair que X_n est un majorant de B et que $X_n \in F_{(\mathcal{E},\mathcal{H})}$.

<u>Si B est infini</u>: alors B est dénombrable, donc B peut se mettre sous la forme $\{X_0, X_1, \ldots X_i, \ldots\}$ où pour tout $i \in IN$ et $j \in IN$ si $i < j$ alors $X_i \subset X_j$; car B est une chaîne infinie de $F_{(\mathcal{E},\mathcal{H})}$.

posons $M = \bigcup_{X\in B} X = \bigcup_{i\in IN} X_i$ qui est donc un ensemble d'instances sans variable de règles contingentes. Il est clair que M est infini dénombrable.
Montrons que M est un majorant de B. Nous aurons donc montré que $F_{(\mathcal{E},\mathcal{H})}$ est inductif.

i Pour tout élément Y de B, il est clair que $Y \subseteq M = \bigcup_{X\in B} X$

ii Montrons que $M \in F_{(\mathcal{E},\mathcal{H})}$.

Nous devons donc montrer qu'il existe $A \in E_{(\mathcal{E},\mathcal{H})}$ tel que $M = \bigcup_{(R,P)\in A}\{R\}$

- Puisque M est infini dénombrable alors il est clair qu'il existe $h : IN \to M$ qui est une bijection.
- Posons $P_i = \{P /$ tel que P est un précepte associé à $h(i)\}$. L'ensemble des hypothèses étant fini, il est clair que pour tout $i \in IN$, P_i est fini.
- Pour tout $i \in IN$, $X_i \in F_{(\mathcal{E},\mathcal{H})}$. Il existe donc $C \in E_{(\mathcal{E},\mathcal{H})}$ tel que $X_i = \bigcup_{(R,P)\in C}\{R\}$. Posons C_i un tel C. Puisque $C_i \in E_{(\mathcal{E},\mathcal{H})}$ il existe donc une interprétation $I \in \mathcal{I}_{\mathcal{E}}$ tel que pour tout $(R,P) \in C_i$, P est vrai pour I, et ceci pour tout $i \in IN$.

Soit $(A_0,N_0), (A_1,N_1), \ldots, (A_i,N_i), \ldots$ la suite construite comme suit:

<u>i=0</u>: Puisque $h(0) \in M = \bigcup_{i\in IN} X_i$ alors il existe $k \in IN$ / $h(0) \in X_k$. Mais puisque $X_0, X_1, \ldots X_i, \ldots$ est une chaîne alors pour tout $j \in IN$ tel que $k \le j$, $h(0) \in X_j$. D'après la définition des C_j il existe donc pour chaque C_j / $k \le j$, $P \in P_0$ tel que $(h(0),P) \in C_j$. Mais $\{X \in IN / k \le X\}$ étant infini et P_0 étant fini, il est clair qu'il existe au

moins un $P \in P_0$ tel que pour tout $j \in \mathbb{N}$ et $k \leq j$ il existe $i \in \mathbb{N}$ / $j < i$ tel que $(h(0),P) \in C_i$. Notons D_0 un tel P.
Posons $A_0=(h(0),D_0)$.
Posons $N_0=\{i \in \mathbb{N} / (h(0),D_0) \in C_i\}$. Il est clair que N_0 est infini dénombrable.

i∈IN : Supposons que N_{i-1} est un ensemble infini dénombrable qui est inclus dans IN.

Puisque $h(i) \in M = \bigcup_{i \in \mathbb{N}} X_i$ alors il existe $k \in \mathbb{N}$ / $h(i) \in X_k$. Mais puisque $X_0, X_1, \ldots X_i, \ldots$ est une chaîne alors pour tout $j \in \mathbb{N}$ tel que $k \leq j$, $h(i) \in X_j$. Donc il existe $k' \in N_{i-1}$ tel que pour tout $j \in N_{i-1}$ tel que $k' \leq j$, $h(i) \in X_j$. D'après la définition des C_j il existe donc pour chaque C_j / $j \in N_{i-1}$ et $k' \leq j$, $P \in P_i$ tel que $(h(i),P) \in C_j$. Mais $\{X \in N_{i-1} / k' \leq X\}$ étant infini et P_i étant fini, il est clair qu'il existe au moins un $P \in P_i$ tel que pour tout $j \in N_{i-1}$ et $k' \leq j$ il existe $g \in N_{i-1}$ / $j < g$ tel que $(h(i),P) \in C_g$ Notons D_i un tel P.
Posons $A_i=(h(i),D_i)$.
Posons $N_i=\{g \in N_{i-1} / (h(i),D_i) \in C_g\}$. Il est clair que N_i est infini dénombrable.
N_0 étant infini dénombrable, et puisque si N_{i-1} est infini dénombrable alors N_i est infini dénombrable il est clair que pour tout $i \in \mathbb{N}$, N_i est infini dénombrable. Notre suite est donc bien définie.

Posons $A=\bigcup_{i \in \mathbb{N}} \{A_i\}$. Par construction nous avons que $A \subseteq D_{\mathcal{H}}$ c'est à dire $A \in \mathcal{P}(D_{\mathcal{H}})$.

(1) Par construction des $A_i=(h(i),D_i)$ il est clair que $M= \bigcup_{(R,P) \in A} \{R\}$.

(2) Montrons que $A \in E_{(\mathcal{E},\mathcal{H})}$ c'est à dire qu'il existe une interprétation $I \in \mathcal{I}_{\mathcal{E}}$ tel que pour tout $(R,P) \in A$, P est vrai pour I. C'est à dire que $\mathcal{E} \cup (\bigcup_{(R,P) \in A} P) = \mathcal{E} \cup (\bigcup_{i \in \mathbb{N}} D_i)$ a un modèle.

Pour cela montrons que toute partie finie de $\mathcal{E} \cup (\bigcup_{i \in \mathbb{N}} D_i)$ a un modèle. En effet un tel ensemble fini peut se mettre sous la forme $F \cup G$ où $F \subseteq \mathcal{E}$, et $G \subseteq A = \bigcup_{i \in \mathbb{N}} D_i$ et F ainsi que G sont finis.

Puisque G est fini et que $G \subseteq \bigcup_{i \in \mathbb{N}} D_i$ il est clair qu'il existe $k \in \mathbb{N}$ tel que $G \subseteq \bigcup_{i \leq k} D_i$. Or par construction des D_i il est clair que pour tout $g \in N_k$, $(\bigcup_{i \leq k} \{(h(i),D_i)\}) \subseteq C_g$. Or pour tout $i \in \mathbb{N}$, il existe une interprétation $I \in \mathcal{I}_{\mathcal{E}}$ tel que pour tout $(R,P) \in C_i$, P est vrai pour I. Donc $\mathcal{E} \cup (\bigcup_{i \leq k} D_i)$ a un modèle et par la suite $F \cup G$ a un modèle car $F \subseteq \mathcal{E}$ et $G \subseteq \bigcup_{i \leq k} D_i$.

Donc tout sous-ensemble fini de $\mathcal{E} \cup (\bigcup_{i \in \mathbb{N}} D_i)$ a un modèle. Mais alors par le théorème de compacité qui dit que :
"<u>Soit Σ un ensemble dénombrable de formules. Si toute partie finie de Σ a un modèle alors Σ a un modèle.</u>"

nous pouvons dire que $\mathcal{E} \cup (\bigcup_{i \in \mathbb{N}} D_i)$ a un modèle. C'est à dire qu'il existe une interprétation $I \in \mathcal{I}_{\mathcal{E}}$ tel que pour tout $(R,P) \in A$, P est vrai pour I .
Donc $A \in E_{(\mathcal{E},\mathcal{H})}$.
Par la suite, par (1) et (2) nous pouvons affirmer que $M \in F_{(\mathcal{E},\mathcal{H})}$.
Donc par i et ii M est élément maximal de B dans $F_{(\mathcal{E},\mathcal{H})}$.
Mais alors toute chaîne (finie ou infinie) B de $F_{(\mathcal{E},\mathcal{H})}$ admet un majorant dans $F_{(\mathcal{E},\mathcal{H})}$ .. Nous avons donc montré que $F_{(\mathcal{E},\mathcal{H})}$ est inductif.
Mais alors grace au théorème de Zorn qui dit que :
"<u>Tout ensemble inductif admet au moins un élément maximal.</u>"
Nous pouvons dire que $F_{(\mathcal{E},\mathcal{H})}$ admet au moins un élément maximal.

■■■

6.4. Définition modèles Cartésiens & Univers Cartésiens

Soit $(\mathcal{E},\mathcal{H})$ une théorie cartésienne où $\mathcal{H}$ est fini.

Posons $N_{(\mathcal{E},\mathcal{H})}=\{C\in F_{(\mathcal{E},\mathcal{H})}$ tel que C est maximal par rapport à $\subseteq$ }. D'après le théorème 6.3 $N_{(\mathcal{E},\mathcal{H})}$ n'est pas vide.

Soit $\mathcal{P}(\mathcal{I}_{\mathcal{E}})$ l'ensemble des parties de $\mathcal{I}_{\mathcal{E}}$.

Soit l'application $f : N_{(\mathcal{E},\mathcal{H})} \to \mathcal{P}(\mathcal{I}_{\mathcal{E}})$ telle que :

$f(C)=\{I\in\mathcal{I}_{\mathcal{E}}$ tel que pour tout $R\in C$, R est vrai pour I }. C'est à dire que I est un modéle de $\mathcal{E}\cup C$.

Soit $\mathcal{I}_{(\mathcal{E},\mathcal{H})}=\bigcup_{C\in N_{(\mathcal{E},\mathcal{H})}} f(C)$ qui est donc un ensemble de modèles de $\mathcal{E}$. Si $I\in\mathcal{I}_{(\mathcal{E},\mathcal{H})}$ nous dirons que I est un modèle Cartésien de $(\mathcal{E},\mathcal{H})$.

Soit $\mathcal{V}_{(\mathcal{E},\mathcal{H})}=\{f(C)$ tel que $C\in N_{(\mathcal{E},\mathcal{H})}\}$ qui est donc un ensemble d'ensembles de modèles de $\mathcal{E}$. Si **$U\in\mathcal{V}_{(\mathcal{E},\mathcal{H})}$ nous dirons que U est un Univers Cartésien de $(\mathcal{E},\mathcal{H})$.**

On peut remarquer que $\mathcal{I}_{(\mathcal{E},\mathcal{H})}\subseteq\mathcal{I}_{\mathcal{E}}$.

Il est clair que pour tout univers Cartésien U, $U\subseteq\mathcal{I}_{(\mathcal{E},\mathcal{H})}$.

Il est clair que $\bigcup_{X\in\mathcal{V}(\mathcal{E},\mathcal{H})} X=\mathcal{I}_{(\mathcal{E},\mathcal{H})}$

6.5. Théorème

Pour toute théorie Cartésienne $(\mathcal{E},\mathcal{H})$ où $\mathcal{H}$ est fini, U est un Univers Cartésien de la théorie Cartésienne $(\mathcal{E},\mathcal{H})$ si et seulement si U est l'ensemble des modèles d'une présomption maximale de $(\mathcal{E},\mathcal{H})$.

Démonstration: I D'après la définition 6.4 si U est un Univers Cartésien de la théorie Cartésienne $(\mathcal{E},\mathcal{H})$ alors il existe $C\in N_{(\mathcal{E},\mathcal{H})}$ tel que $U=f(C)$.

Montrons que pour tout $C\in N_{(\mathcal{E},\mathcal{H})}$, $\mathcal{E}\cup C$ est une présomption maximale de $(\mathcal{E},\mathcal{H})$ telle que $f(C)$ est l'ensemble des modèles de $\mathcal{E}\cup C$.

D'aprés la définition 6.4 il est clair que $f(C)$ est l'ensemble des modèle de $\mathcal{E}\cup C$.

Montrons que $\mathcal{E}\cup C$ est une présomption maximale de $(\mathcal{E},\mathcal{H})$.

Montrons tout d'abord que $\mathcal{E}\cup C$ est une présomption de $(\mathcal{E},\mathcal{H})$.

Puisque $C\in N_{(\mathcal{E},\mathcal{H})}$ alors $C\in F_{(\mathcal{E},\mathcal{H})}$, donc il existe $B\in E_{(\mathcal{E},\mathcal{H})}$/ $C=\bigcup_{(R,P)\in B}\{R\}$.

Soit $A=\bigcup_{(R,P)\in B} P$, il est clair que A est un apriori de C.

Mais puisque $B\in E_{(\mathcal{E},\mathcal{H})}$ il existe donc une interprétation $I\in\mathcal{I}_{\mathcal{E}}$ telle que pour tout $(R,P)\in B$, P est vrai pour I, par la suite I est un modèle de A. Donc puisque la déduction est juste et que $I\in\mathcal{I}_{\mathcal{E}}$, $\mathcal{E}\cup A\nvdash\bot$. Donc A est un apriori de C tel que $\mathcal{E}\cup A\nvdash\bot$, donc C est une présomption de $(\mathcal{E},\mathcal{H})$.

Montrons que $\mathcal{E}\cup C$ est maximale.

Supposons que $\mathcal{E}\cup D$ est une présomption de $(\mathcal{E},\mathcal{H})$ telle que $C\subseteq D$.

Soit $B=\{(R,P)$ tel que $R\in D$ et P est un précepte associé à $R\}$ tel que $\mathcal{E}\cup\bigcup_{(R,P)\in B} P\nvdash\bot$. Un tel B existe car $\mathcal{E}\cup D$ est une présomption. il est clair qu'alors $\bigcup_{(R,P)\in B} P$ est un apriori de D. Nous avons $D=\bigcup_{(R,P)\in B}\{R\}$ et $B\in E_{(\mathcal{E},\mathcal{H})}$ puisque $\mathcal{E}\cup\bigcup_{(R,P)\in B} P\nvdash\bot$ et que la déduction est juste et complète. Donc $D\in F_{(\mathcal{E},\mathcal{H})}$. Mais $C\subseteq D$, et puisque C est maximale dans $F_{(\mathcal{E},\mathcal{H})}$ car $C\in N_{(\mathcal{E},\mathcal{H})}$ alors $C=D$. Par la suite $\mathcal{E}\cup C$ est maximale.

II Inversement : Supposons que U est l'ensemble des modèles de $\mathcal{E}\cup M$ une présomption maximale de $(\mathcal{E},\mathcal{H})$.

Montrons qu'alors $M\in N_{(\mathcal{E},\mathcal{H})}$, c'est à dire que $U=f(M)$, donc que U est un univers cartésien de $(\mathcal{E},\mathcal{H})$.

Montrons tout d'abord que $M\in F_{(\mathcal{E},\mathcal{H})}$.

Soit $B=\{(R,P)$ tel que $R\in M$ et P est un précepte associé à $R\}$ tel que $\mathcal{E}\cup\bigcup_{(R,P)\in B}P \nvdash \perp$. Un tel B existe car $\mathcal{E}\cup M$ est une présomption. Il est clair qu'alors $\bigcup_{(R,P)\in B}P$ est un apriori de M Nous avons $M=\bigcup_{(R,P)\in B}\{R\}$ et $B\in E_{(\mathcal{E},\mathcal{H})}$ puisque $\mathcal{E}\cup\bigcup_{(R,P)\in B}P \nvdash \perp$ et que la déduction est juste et complète. Donc $M\in F_{(\mathcal{E},\mathcal{H})}$.
Montrons que M est maximal dans $F_{(\mathcal{E},\mathcal{H})}$, donc que $M\in N_{(\mathcal{E},\mathcal{H})}$.
Supposons que $E\in F_{(\mathcal{E},\mathcal{H})}$ et que $M\subseteq E$.

Puisque $E\in F_{(\mathcal{E},\mathcal{H})}$ alors il existe $B\in E_{(\mathcal{E},\mathcal{H})}$/ $E=\bigcup_{(R,P)\in B}\{R\}$.

Soit $A=\bigcup_{(R,P)\in B}P$, il est clair que A est un apriori de E
Mais puisque $B\in E_{(\mathcal{E},\mathcal{H})}$ il existe donc une interprétation $I\in \mathcal{I}_{\mathcal{E}}$ telle que pour tout $(R,P)\in B$, P est vrai pour I, par la suite I est un modèle de A. Donc puisque la déduction est juste et que $I\in\mathcal{I}_{\mathcal{E}}$, $\mathcal{E}\cup A\nvdash\perp$. Donc A est un apriori de E tel que $\mathcal{E}\cup A\nvdash\perp$, donc $\mathcal{E}\cup E$ est une présomption de $(\mathcal{E},\mathcal{H})$. Mais $\mathcal{E}\cup M$ étant une présomption maximale il est clair qu'alors $E=M$ Mais alors M est maximal dans $F_{(\mathcal{E},\mathcal{H})}$.

■■■

6.6. Théorème

Pour toute théorie Cartésienne $(\mathcal{E},\mathcal{H})$ telle que $\mathcal{H}$ est fini, I est un modèle Cartésien de la théorie Cartésienne $(\mathcal{E},\mathcal{H})$ si et seulement si I est lun modèle d'une extention Maximale de $(\mathcal{E},\mathcal{H})$.

Démonstratio:□□□ D'après la définition 6.4 I est un modèle Cartésien de $(\mathcal{E},\mathcal{H})$ si et seulement si il existe $C\in N_{(\mathcal{E},\mathcal{H})}$ tel que $I\in\int(C)$ qui est un univers Cartésien. Et par le théorème 6.5 $\int(C)$ est un univers Cartésien si et seulement si c'est lensemble des modèles d'une extention maximale de $(\mathcal{E},\mathcal{H})$. Donc I est un modèle Cartésien de la théorie Cartésienne $(\mathcal{E},\mathcal{H})$ si et seulement si I est un modèle d'une extention Maximale de $(\mathcal{E},\mathcal{H})$. ■■■

6.7. Définition Conséquences cartésiennes

Soit une théorie Cartésienne $(\mathcal{E},\mathcal{H})$ où $\mathcal{H}$ est fini, f une formule. On dira que **f est une conséquence Cartésienne de $(\mathcal{E},\mathcal{H})$ si et seulement si il existe un univers Cartésien U de $(\mathcal{E},\mathcal{H})$ tel que f est vrai pour tous les modèles appartenants à U.**

6.8. Théorème

Pour toute théorie Cartésienne $(\mathcal{E},\mathcal{H})$ telle que $\mathcal{H}$ est fini, une formule f est présumable pour $(\mathcal{E},\mathcal{H})$ si et seulement si c'est une conséquence Cartésienne de $(\mathcal{E},\mathcal{H})$.

Démonstration:□□□ I Par le théorème 4.4 nous avons vu que si une formule f est présumable pour $(\mathcal{E},\mathcal{H})$ alors il existe une conjecture $\mathcal{C}$ de $(\mathcal{E},\mathcal{H})$ telle que $f\in\mathcal{C}$. Une conjecture de $(\mathcal{E},\mathcal{H})$ étant l'ensemble des théorèmes d'une présomption maximale de $(\mathcal{E},\mathcal{H})$, et la déduction étant juste il est clair qu'il existe $\mathcal{E}\cup M$ une présomption maximale de $(\mathcal{E},\mathcal{H})$ telle que f est vrai pour tous les modèles de $\mathcal{E}\cup M$ Donc par le théorème 6.5 il existe U un univers cartésien de $(\mathcal{E},\mathcal{H})$ tel que f est vrai pour tout les modèles appartenant à U Par la suite f est une conséquence Cartésienne de $(\mathcal{E},\mathcal{H})$.

II Si f est une conséquence Cartésienne de $(\mathcal{E},\mathcal{H})$, il existe un univers Cartésien U de $(\mathcal{E},\mathcal{H})$ tel que f est vrai pour tous les modèles appartenants à U, alors par le théorème 6.5 il existe $\mathcal{E}\cup M$ une présomption maximale de $(\mathcal{E},\mathcal{H})$ telle que f est vrai pour tous les modèles de $\mathcal{E}\cup M$ Mais alors la déduction étant complète il est clair que f est un théorème de $\mathcal{E}\cup M$, Mais alors f est présumable pour $(\mathcal{E},\mathcal{H})$. ■■■

6.9. Exemple Une théorie Cartésienne ses modèles et ses univers

Soit la théorie Cartésienne suivante :

(1)	Effectif	a	} $\mathcal{E}$
(2)	Contingent	b : {b, ˥a}	
(3)	Contingent	b : {b, ˥c, ˥d}	
(4)	Contingent	b : {b,c}	$\mathcal{H}$
(5)	Contingent	˥b : {˥b}	
(6)	Contingent	d : {d, ˥c}	
(7)	Contingent	c : {c, ˥d}	

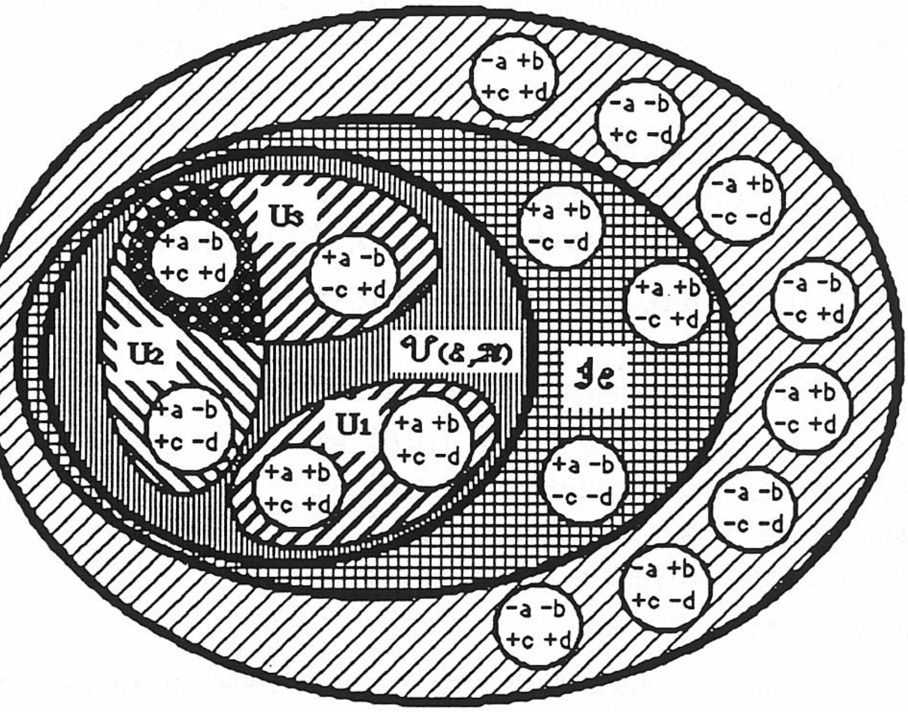
La théorie Cartésienne $(\mathcal{E},\mathcal{H})$ a trois présomptions maximales :

$E_1=\{a\}\cup\{b,c\}$ car : $\{a\}\cup(\{b,c\}\cup\{c,\neg d\})\nvdash\perp$

$E_2=\{a\}\cup\{\neg b,c\}$ car : $\{a\}\cup(\{\neg b\}\cup\{c,\neg d\})\nvdash\perp$

$E_3=\{a\}\cup\{\neg b,d\}$ car : $\{a\}\cup(\{\neg b\}\cup\{d,\neg c\})\nvdash\perp$

La théorie Cartésienne $(\mathcal{E},\mathcal{H})$ a cinq modèles cartésiens et trois univers Cartésiens U_1, U_2, U_3. (Voir la figure 6.10 où (-a -b +c +d) représente l'interprétation qui assigne la valeur de vérité **Faux** aux propositions a et b et la valeur de vérité **Vrai** aux propositions c et d, c'est à dire : **Vrai** à une proposition qui est précédée d'un +; **Faux** à une proposition qui est précédée d'un - .)



6.10. Figure

6.11. Remarque Justifications coopératives & modèles cartésiens

Ici b est une formule présumable pour $(\mathcal{E},\mathcal{H})$ et [b, ˥c, ˥d] en est une des justifications coopératives. Car $\{a\}\cup\{b\}\vdash b$, et $\{a\}\cup\{b,\neg c,\neg d\}\nvdash\perp$. Ce qui ne veut pas dire qu'il existe nécessairement un modèle cartèsien de le théorie cartésienne $(\mathcal{E},\mathcal{H})$ telle que b et ˥c et ˥d soit vrai dans un tel modèle. D'ailleurs ici il n'existe pas un tel modèle cartésien de la théorie cartésienne $(\mathcal{E},\mathcal{H})$.

6.12. Remarque Les notations $\vdash^{c}$ et $\models^{c}$

Nous avons défini en 2.6 ce qu'est une formule présumable d'une théorie cartésienne $(\mathcal{E},\mathcal{H})$, ce qui est une notion syntaxique.

Nous avons défini en 6.7 ce qu'est une conséquence cartésienne d'une théorie cartésienne $(\mathcal{E},\mathcal{H})$ o $\mathcal{H}$ est fini, ce qui est une notion sémantique.

Nous avons montré par le théorème 6.8 que pour toute théorie cartésienne $(\mathcal{E},\mathcal{H})$ où $\mathcal{H}$ est fini, qu f est une formule présumable de la théorie cartésienne $(\mathcal{E},\mathcal{H})$ si et seulement si f est une conséquen cartésienne de la théorie cartésienne $(\mathcal{E},\mathcal{H})$.

Nous noterons $(\mathcal{E},\mathcal{H}) \mid\!\sim^{c} f$ pour exprimer que f est une formule présumable de $(\mathcal{E},\mathcal{H})$.

Nous noterons $(\mathcal{E},\mathcal{H}) \mid\!\approx^{c} f$ pour exprimer que f est une conséquence cartésienne de $(\mathcal{E},\mathcal{H})$.

Si $\mathcal{H}$ est nini, nous avons donc que $(\mathcal{E},\mathcal{H}) \mid\!\sim^{c} f$ si et seulement si $(\mathcal{E},\mathcal{H}) \mid\!\approx^{c} f$.

6.13. Remarque Quatre sortes de conséquences

Nous pouvons définir quatre sortes de conséquences d'une théorie cartésienne $(\mathcal{E},\mathcal{H})$.

(Sorte_1) f est une conséquence de sorte_1 de $(\mathcal{E},\mathcal{H})$ si f est conséquence logique de $\mathcal{E}$. C'est à dir $\mathcal{E} \models f$. Il est clair que f est conséquence de sorte_1 de $(\mathcal{E},\mathcal{H})$ si et seulement si f est affirmable pour $(\mathcal{E},\mathcal{H})$
Dans l'exemple 6.9, a est conséquence de sorte_1 de $(\mathcal{E},\mathcal{H})$.

(Sorte_2) f est une conséquence de sorte_2 de $(\mathcal{E},\mathcal{H})$ si f est vrai dans tous les modèles cartésiens d $(\mathcal{E},\mathcal{H})$.
Dans l'exemple 6.9 $\neg b \vee c$ est conséquence de sorte_2 de $(\mathcal{E},\mathcal{H})$.

(Sorte_3) f est une conséquence de sorte_3 de $(\mathcal{E},\mathcal{H})$ si il existe U un univers cartésien de $(\mathcal{E},\mathcal{H})$ te que f est vrai dans tous les modèles de U; Et que pour tout univers cartésien U1 de $(\mathcal{E},\mathcal{H})$, f n'est pas fau dans tous les modéles de U1.

C'est à dire $(\mathcal{E},\mathcal{H}) \mid\!\approx^{c} f$ et $(\mathcal{E},\mathcal{H}) \not\mid\!\approx^{c} \neg f$.

Dans l'exemple 6.9 c est conséquence de sorte_3 de $(\mathcal{E},\mathcal{H})$.

(Sorte_4) f est une conséquence de sorte_4 de $(\mathcal{E},\mathcal{H})$ si il existe U un univers cartésien de $(\mathcal{E},\mathcal{H})$ te que f est vrai dans tous les modèles de U. C'est à dire $(\mathcal{E},\mathcal{H}) \mid\!\approx^{c} f$ (f est conséquence cartésienne de $(\mathcal{E},\mathcal{H}$).

Dans l'exemple 6.9 $a \wedge b \wedge c$ est conséquence cartésienne de $(\mathcal{E},\mathcal{H})$.

Soit A_1 l'ensemble des conséquences de sorte_1 de $(\mathcal{E},\mathcal{H})$.
Soit A_2 l'ensemble des conséquences de sorte_2 de $(\mathcal{E},\mathcal{H})$.
Soit A_3 l'ensemble des conséquences de sorte_3 de $(\mathcal{E},\mathcal{H})$.
Soit A_4 l'ensemble des conséquences cartésiennes de $(\mathcal{E},\mathcal{H})$.

Alors il est clair que $A_1 \subseteq A_2 \subseteq A_3 \subseteq A_4$.

Pour le cas particulier où l'ensemble des connaissances sûres et l'ensemble des hypothèses supposabl peuvent être codés à partir de clauses générales du calcul des prédicats, nous avons développé u démonstrateur automatique de formules présumables. Ce démonstrateur chargé avec une théor Cartésienne $(\mathcal{E},\mathcal{H})$ peut être interrogé sur la présumabilité d'une formule (une clause générale) et réponse est accompagnée d'une justification coopérative. L'idée est la suivante. Pour un but b donné, o cherche a résoudre b à partir de $\mathcal{E}$ et des règles contingentes. A chaque fois que l'on utilise une instence F de règle contingente R (qui apparait donc dans une hypothèse H de la forme (R,P)) on met en réserve F le précepte associé à $P\theta$. Si la résolution aboutit on vérifie alors la consistence avec $\mathcal{E}$ de l'ensemble d préceptes associés utilisés. Si c'est le cas alors cet ensemble est une justification coopérative de la réponse.

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A tableaux-based engine for geometrical reasoning

by Philippe Balbiani and Luis Fariñas del Cerro*

Presque toutes nos actions simples ou savemment constituées sont des applications de notions géométriques.

Simone Weil (L'enracinement, 1945)

1. Introduction

Using two elementary notions: betweeness and equidistance, which respectively formalize the ruler and the compass, Tarski [13] gives an answer to the question: what is elementary geometry ?. He considers that points are the unique elements of the geometrical universe and that betweeness and equidistance are the tools for relating points.

Tarski's set of axioms for euclidean geometry consists in 13 axioms (as a matter of fact, some of these axioms are dependant of the others and can be eliminated). Variants of this theory, like Bolyai-Lobachevsky geometry, can be easily obtained replacing some axioms of this theory.

This report has two aims. Firstly, we give an automated deduction method, in a tableaux style, for the two dimensional euclidean geometry. Such methods could be extended to non-classical geometry as well. Secondly, we wish to rehabilitate greek's vision of the relation between numbers and geometry, in the sense that they considered numbers and arithmetical operations on them as representations of geometrical construction.

Following Tarski [13], we consider a first order language with two specific predicates, B and Eq: B(x,y,z) means that y is between x and z and Eq(x,y,z,u) means that x is as distant from y as z is from u. The characteristic axioms of elementary euclidean geometry consists of twelve axioms, A1, ..., A12, and an infinite collection of elementary continuity axioms, A13 (see the annex). We should notice that the continuity axiom is an infinite collection of elementary axioms.

Tarski denotes the elementary geometry theory based upon the axioms listed in our annex by $\mathcal{E}_2$. He proves that for $\mathcal{M}$ to be a model of $\mathcal{E}_2$, it is necessary and sufficient that $\mathcal{M}$ be isomorphic with the cartesian space $\mathfrak{C}_2(\mathcal{F})$ over some real closed field $\mathcal{F}$. Moreover, since a

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sentence formulated in $\mathcal{E}_2$ is valid if and only if it holds in $\mathcal{C}_2(\mathcal{R})$, the cartesian space over $\mathcal{R}$, he concludes that the theory $\mathcal{E}_2$ is complete, consistent and decidable.

2. Tableaux for elementary geometry

Several geometrical theorem provers have been defined during the last few years [2], [3], [5], [6], [7], [8], [10]. The first one is the "geometry machine" of Gelernter [5]. Coelho and Pereira [3] and, later, Quaife[10], using similar methodology implemented respectively in Prolog and Otter [9], developed geometrical deduction systems based upon some logical formalization of euclidean geometry. Algebra, after Descartes, can be considered as an alternative approach. Tarski [12] has inaugurated the algebraic method by his decision method for algebra and geometry. Collins [4] improved Tarski's method. Nevertheless, Wu's method [2][14] is considered as the first one for which realistic implementations can be given. Algebraic methods are able to prove difficult theorems. However, it is very hard to stress geometrical constructions from proofs and to have comprehensive traces of these proofs.

The method presented in this section tries to make up for these problems. Our approach comes from logic and reflects directly Tarski's axiomatization of the euclidean plane. Following Smullyan [11], we use the unifying notation for the tree proof procedure called analytic tableaux. For euclidean geometry, rules for the construction of tableaux are those of first order logic (for special purpose that will be detailed later, we will need a special rule that will be called the $\gamma\delta\delta$-rule and which could be used on signed formulas of the form $+\forall z\, \exists x\, \exists y\, F(z,x,y)$ or $-\exists z\, \forall x\, \forall y\, F(z,x,y)$) together with fifteen geometrical rules.

The classical rules are:

$\dfrac{\alpha}{\alpha_1 \;\; \alpha_2}$	$\dfrac{\beta}{\beta_1 \mid \beta_2}$	$\dfrac{\gamma}{\gamma(x)}$	$\dfrac{\delta}{\delta(f(x_1,\ldots,x_n))}$
		x being a new free variable	f being a new function symbol and $x_1,\ldots,x_n$ being the variables introduced using the γ-rule or the $\gamma\delta\delta$-rule

$$\frac{\gamma\delta\delta}{\gamma\delta\delta(u,f(x_1,\ldots,x_n,u),g(x_1,\ldots,x_n,u)) \quad \gamma\delta\delta(v,f(x_1,\ldots,x_n,v),g(x_1,\ldots,x_n,v))}$$

u and v being new free variables, f and g being new function symbols and $x_1,\ldots,x_n$ being the variables introduced using

the γ-rule or the $\gamma\delta\delta$-rule, $\gamma\delta\delta$ being a formula of the form
$+\forall z\ \exists x\ \exists y\ F(z,x,y)$ or $-\exists z\ \forall x\ \forall y\ F(z,x,y)$

The geometrical rules are:

R1 $\dfrac{+B(x,y,x)}{+(x = y)}$ R2 $\dfrac{+B(x,y,u)\quad +B(y,z,u)}{+B(x,y,z)}$

R3 $\dfrac{+B(x,y,z)\quad +B(x,y,u)}{+(x = y) \mid +B(x,z,u) \mid +B(x,u,z)}$ R4 $\dfrac{}{+Eq(x,y,y,x)}$

R5 $\dfrac{+Eq(x,y,z,z)}{+(x = y)}$ R6 $\dfrac{+Eq(x,y,z,u)\quad +Eq(x,y,v,w)}{+Eq(z,u,v,w)}$

R7 $\dfrac{+B(x,t,u)\quad +B(y,u,z)}{+B(x,Pasch(t,x,y,z,u),y)\quad +B(z,t,Pasch(t,x,y,z,u))}$

R8a $\dfrac{+B(x,u,t)\quad +B(y,u,z)}{+(x = y) \mid +B(x,z,E1(t,x,y,z,u))}$

R8b $\dfrac{+B(x,u,t)\quad +B(y,u,z)}{+(x = y) \mid +B(x,y,E2(t,x,y,z,u))}$

R8c $\dfrac{+B(x,u,t)\quad +B(y,u,z)}{+(x = y) \mid +B(E1(t,x,y,z,u),t,E2(t,x,y,z,u))}$

R9 $\dfrac{\begin{array}{c}+B(x,y,z)\quad +B(x',y',z')\\ +Eq(x,y,x',y')\quad +Eq(y,z,y',z')\quad +Eq(x,u,x',u')\quad +Eq(y,u,y',u')\end{array}}{+(x = u) \mid +Eq(z,u,z',u')}$

R10 $\dfrac{}{+B(x,y,Seg(x,y,u,v))\quad +Eq(y,Seg(x,y,u,v),u,v)}$

R11 $\dfrac{}{-B(a,b,c)\quad -B(b,c,a)\quad -B(c,a,b)}$

R12 $\dfrac{+Eq(x,u,x,v)\wedge Eq(y,u,y,v)\wedge Eq(z,u,z,v)}{+(u = v) \mid +B(x,y,z) \mid +B(y,z,x) \mid +B(z,x,y)}$

R13 $\dfrac{+B(a,f(y),g(z))}{+B(f(u),b,g(v))}$

Rules R1 to R13 correspond to Tarski's axioms given in the annex. The last rule R13 should be used under some special restrictions for it corresponds to the infinite set of elementary continuity axioms. The branch of the tableaux should contain a formula of the type $B(a,f_i(y_j),f_k(y_l))$ where a is a Skolem constant introduced with the δ-rule, where b is a new Skolem constant, where f_i and f_k are distinct unary Skolem functions introduced with the γδδ-rule and where y_j and y_l are distinct variables introduced with the γδδ-rule.

This rule R13 is very powerful since it will enable us to close the tableaux of every negated instance of the elementary continuity axiom schema. It is the geometrical counterpart of Dedekind cut for the construction of real numbers: it says that if the values of the functions f and g are colinear and non-overlapping sets of points of the euclidean plane then there is a point, say b, between these two sets.

Theorem. soundness and completeness of our rules for the construction of tableaux. *For a sentence F formulated in $\mathscr{E}_2$ to be a theorem it is necessary and sufficient that the tableau associated to -F be closed*

Proof. The completeness is proved showing that the tableaux of every negated axiom is closed. It is not difficult and we only deal with negated instances of axiom schema A13:

1	$- \forall vw... \{\exists z \forall xy [\phi(x,v,w,...) \wedge \psi(y,v,w,...) \rightarrow B(z,x,y)] \rightarrow$ $\exists u \forall xy [\phi(x,v,w,...) \wedge \psi(y,v,w,...) \rightarrow B(x,u,y)]\}$
2=δ,α/1	$+\exists z \forall xy [\phi(x,a,b,...) \wedge \psi(y,a,b,...) \rightarrow B(z,x,y)]$
3=δ,α/1	$- \exists u \forall xy [\phi(x,a,b,...) \wedge \psi(y,a,b,...) \rightarrow B(x,u,y)]$
4=δ/2	$+\forall xy [\phi(x,a,b,...) \wedge \psi(y,a,b,...) \rightarrow B(c,x,y)]$
5=γδδ/3	$- [\phi(f(v_1),a,b,...) \wedge \psi(g(v_1),a,b,...) \rightarrow B(f(v_1),v_1,g(v_1))]$
6=γδδ/3	$- [\phi(f(v_2),a,b,...) \wedge \psi(g(v_2),a,b,...) \rightarrow B(f(v_2),v_2,g(v_2))]$
7=α/5	$+ \phi(f(v_1),a,b,...)$
8=α/5	$- B(f(v_1),v_1,g(v_1))$
9=α/6	$+ \psi(g(v_2),a,b,...)$
10=γ/4	$+ [\phi(v_3,a,b,...) \wedge \psi(v_4,a,b,...) \rightarrow B(c,v_3,v_4)]$
11=β/10	$- \phi(v_3,a,b,...) \mid - \psi(v_4,a,b,...) \mid +B(c,v_3,v_4)$
12=11/$\{v_3/f(v_1),v_4/g(v_2)\}$	$+B(c,f(v_1),g(v_2))$
13=R13/12	$+B(f(v_5),d,g(v_6))$
14=8,13	$\perp$

Remark that thanks to the rule γδδ, the tableaux associated to negated instances of the elementary continuity axiom schema can be closed. The expression 2=δ,α/1 (for example) means that the expresion 2 is obtained from 1 applying successively the rules δ and α.

The soundness is proved showing that satisfiability is preserved when a rule is used. Let S be a set of signed formula of elementary geometry such that (∀ S) is satisfiable. Then

($\forall$ S) is true in some model of $\mathcal{E}_2$. This model being isomorphic to the cartesian space $\mathfrak{C}_2(\mathcal{R})$ over $\mathcal{R}$, we have:

($\forall$ S) is true in $\mathfrak{C}_2(\mathcal{R})$

Let us prove that the set S', obtained from S using one of the rules, is such that ($\forall$ S') is true in $\mathfrak{C}_2(\mathcal{R})$. If the rule used is a classical rule α, β, γ, δ or $\gamma\delta\delta$ or a geometrical rule R1, ..., R11 or R12 then ($\forall$ S') is obviously true in $\mathfrak{C}_2(\mathcal{R})$ since these rules are simple translations of classical axioms and axioms A1, ..., A11 and A12. Let us assume that S' is obtained from S using rule R13. Thus S contains some formula B(a,f(x),g(y)), a being a constant, f and g being distinct function symbols introduced with the $\gamma\delta\delta$-rule and x and y being distinct variables introduced with the $\gamma\delta\delta$-rule. Thus, the satisfiability of ($\forall$ S) in $\mathfrak{C}_2(\mathcal{R})$ implies that the three sets:

{a}
{f(x): x is a point of the euclidean plane}
{g(y): y is a point of the euclidean plane}

define colinear and non-overlapping sets of points, the second set being just between the two others. Consequently, there is a point b in $\mathfrak{C}_2(\mathcal{R})$ such that, for every point u and v, b is between f(u) and g(v). Then B(f(u),b,g(v)) can be added to S in such a way that:

($\forall$ (S$\cup$B(f(u),b,g(v)))) is satisfied in $\mathfrak{C}_2(\mathcal{R})$

□

Observe that our tableaux rules provide a decision method for elementary geometry $\mathcal{E}_2$ since $\mathcal{E}_2$ is complete (for every sentence F of $\mathcal{E}_2$, either F or $\neg$F is a theorem): for every sentence F of $\mathcal{E}_2$, either the tableaux of -F or the tableaux of +F is closed.

Rules R8a, R8b and R8c correspond to the Euclid's axiom A8 (see the annex). In this axiom nothing is explicitly said about the fact that the segments [E1(t,x,y,z,u),E2(t,x,y,z,u)] and [y,z] could be parallel. So, we introduce new functions EP1 and EP2. The three following rules can replace rules R8a, R8b and R8c in such a way that the segments [EP1(t,x,y,u,z),EP2(t,x,y,z,u)] and [y,z] are parallel:

R8a' $$\frac{+B(x,u,t)\quad +B(y,u,z)}{+(x = y) \mid +B(x,z,EP1(t,x,y,z,u))}$$

R8b' $$\frac{+B(x,u,t)\quad +B(y,u,z)}{+(x = y) \mid +B(x,y,EP2(t,x,y,z,u))}$$

$$\text{R8c'}\quad \frac{+B(x,u,t)\ +B(y,u,z)}{+(x = y)\mid -Col(EP1(t,x,y,z,u),v,EP2(t,x,y,z,u))\mid -Col(y,v,z)}$$

where $Col(x,y,z)=_{df}B(x,y,z)\vee B(y,z,x)\vee B(z,x,y)$

The soundness and completeness proofs of the tableaux deduction system based upon these new rules are similar to those for the original tableaux system.

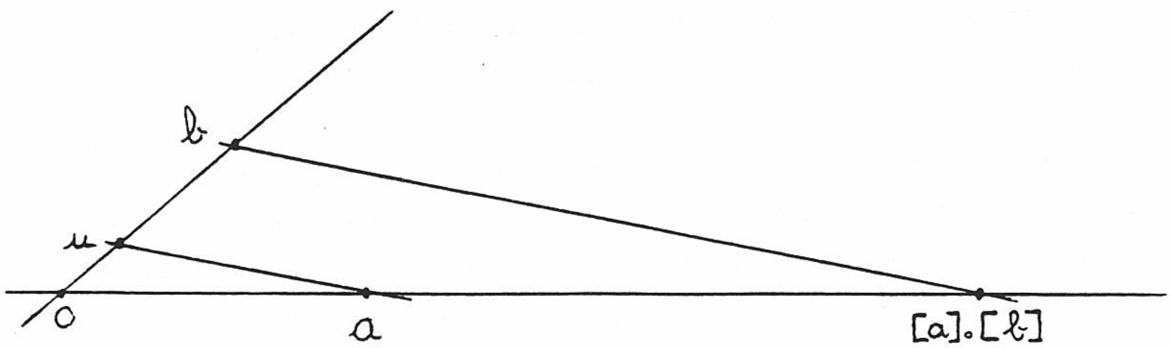
3. From numbers to geometrical constructions; examples

In this section we present two well known geometrical constructions. They will be geometrical representation of addition and multiplication. Numbers are represented by segments (that is to say: pairs of points. We consider an arbitrary point "o" that we call origin. Therefore, each segment [o,a] (or [a] in short) determinates a real number. The unit segment will be denoted by [o,u] and will be used to define the multiplication operation between segments.

[a]+[b], the addition of [a] and [b] is represented by the new point Seg(o,a,o,b). Graphically we have the following construction. If [o,a] and [o,b] are such that: o------a----------b, then [a]+[b] will be the term Seg (o,a,o,b): o------a-----------b------Seg(o,a,o,b).

In the same way, [o,a].[o,b], the multiplication of [o,a] and [o,b], could be represented by the new point EP1(b,o,u,a,u). Thanks to Thales' theorem, we have:

[o,a].[o,b]=[o,u].[o,EP1(b,o,u,a,u)]



Since [o,u] is the unit segment, we have:

[o,a].[o,b]=[o,EP1(b,o,u,a,u)]

These constructions, which are in fact geometrical terms, allow us to consider arithmetical operations as formal manipulations on terms. An important aim of our work is to use geometry as an engine for calculating. In order to stress it and to show how the rules for the construction of tableaux are unfold we are going to present some examples where the continuity rule is used.

We must observe that the existing geometrical theorem provers are not able to use the elementary continuity axiom schema in all generality. For example, Quaife [10] uses a weak version of the continuity axiom which corresponds to the geometrical theory $\mathcal{E}_2''$ obtained from $\mathcal{E}_2$ replacing the axiom schema A13 by the axiom:

A13' [WEAK ELEMENTARY CONTINUITY AXIOM].

$$\forall xyzx'z'u\ \exists y'\ (Eq(u,x,u,x') \land Eq(u,z,u,z') \land B(u,x,z) \land B(x,y,z) \rightarrow Eq(u,y,u,y') \land B(x',y',z'))$$

In this respects, Quaife imposes restrictions on the quantification of the formulas to be proved. He considers only the class of universally quantified formulas for which Tarski [13] proved the decidability. As a matter of fact, a universally quantified sentence is a theorem of $\mathcal{E}_2''$ if and only if it is a theorem of $\mathcal{E}_2$. Similar restriction are oftenly considered in algebraic methods. Thus some of the examples presented in this section could not be handled directly by these kind of methods. For example, Wu's algorithm could not solve the question: $\forall xy\ (x^2+y^2=0 \rightarrow x=0)$.

example 1. This first example deals with the following formula which says that there is always a point z between two colinear non-overlapping segments [a,b] and [c,d]:

$$\forall abcd\ ((\forall xy\ (B(a,x,b) \land B(c,y,d) \rightarrow B(a,x,y))) \rightarrow (\exists z\ \forall xy\ (B(a,x,b) \land B(c,y,d) \rightarrow B(x,z,y))))$$

Then we have the following closed tableau:

1	$-\forall abcd\ ((\forall xy\ (B(a,x,b) \land B(c,y,d) \rightarrow B(a,x,y))) \rightarrow (\exists z\ \forall xy\ (B(a,x,b) \land B(c,y,d) \rightarrow B(x,z,y))))$
$2=\alpha,\delta/1$	$+(\forall xy\ (B(a,x,b) \land B(c,y,d) \rightarrow B(a,x,y)))$
$3=\alpha,\delta/1$	$-(\exists z\ \forall xy\ (B(a,x,b) \land B(c,y,d) \rightarrow B(x,z,y)))$
$4=\gamma\delta\delta/3$	$-(B(a,f(v_1),b) \land B(c,g(v_1),d) \rightarrow B(f(v_1),v_1,g(v_1)))$
$5=\gamma\delta\delta/3$	$-(B(a,f(v_2),b) \land B(c,g(v_2),d) \rightarrow B(f(v_2),v_2,g(v_2)))$
$6=\alpha/4$	$+B(a,f(v_1),b)$
$7=\alpha/4$	$-B(f(v_1),v_1,g(v_1))$
$8=\alpha/5$	$+B(c,g(v_2),d)$
$9=\gamma/2$	$+(B(a,v_3,b) \land B(c,v_4,d) \rightarrow B(a,v_3,v_4)))$
$10=\beta/9$	$- B(a,v_3,b) \mid - B(c,v_4,d) \mid +B(a,v_3,v_4)$

11=10/{v_3/f(v_1),v_4/g(v_2)}   +B(a,f(v_1),g(v_2))

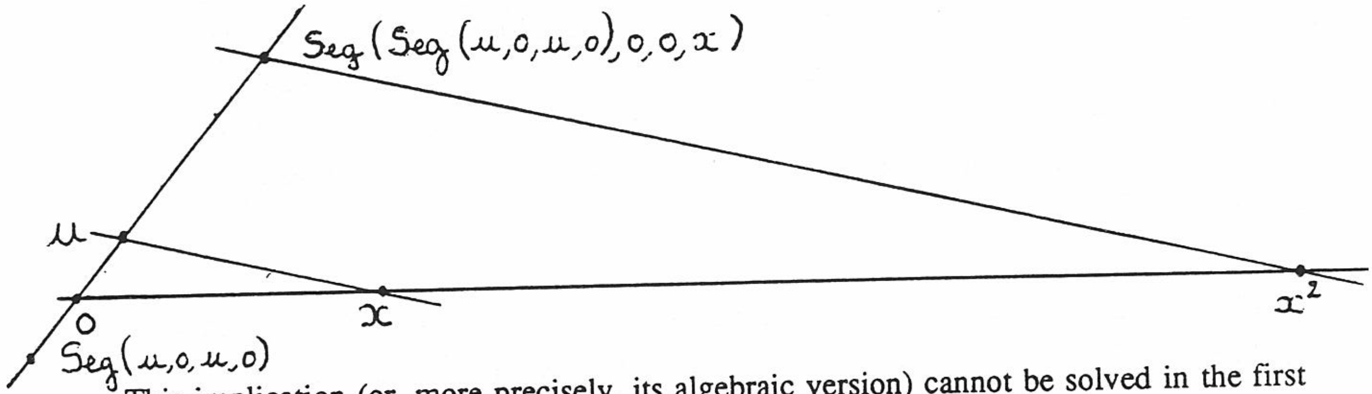
12=R13/11   +B(f(v_5),e,g(v_6))

13=7,12   ⊥

example 2. Our second example is about the polynomial implication: $\forall$ x y ($x^2+y^2=0 \rightarrow$ x=0). Its translation in geometrical means is the following formula:

$\forall$ o u (o≠u $\rightarrow$ ($\forall$ x y (Seg(o,EP1(Seg(Seg(u,o,u,o),o,o,x),o,u,x,u),o,
EP1(Seg(Seg(u,o,u,o),o,o,y),o,u,y,u))=o $\rightarrow$ x=o))

The terms EP1(Seg(Seg(u,o,u,o),o,o,x),o,u,x,u) and EP1(Seg(Seg(u,o,u,o),o,o,y),o,u,y,u) respectively denotes x^2 and y^2. The term Seg(o,EP1(Seg(Seg(u,o,u,o),o,o,x),o,u,x,u),o,EP1(Seg(Seg(u,o,u,o),o,o,y),o,u,y,u)) denotes x^2+y^2.



This implication (or, more precisely, its algebraic version) cannot be solved in the first version of Wu's method. In order to prove it, some refinement of the method has been introduced [2]. However it is no so complicated, using our method, to have the following closed tableaux:

1   -$\forall$ o u (o≠u $\rightarrow$ ($\forall$ x y (Seg(o,EP1(Seg(Seg(u,o,u,o),o,o,x),o,u,x,u),o,
EP1(Seg(Seg(u,o,u,o),o,o,y),o,u,y,u))=o) $\rightarrow$ x=o))

2=δ/1   -(a≠b $\rightarrow$ ($\forall$ x y (Seg(a,EP1(Seg(Seg(b,a,b,a),a,a,x),a,b,x,b),a,
EP1(Seg(Seg(b,a,b,a),a,a,y),a,b,y,b))=a) $\rightarrow$ x=a))

3=α/2   +a≠b

4=α/2   -($\forall$ x y (Seg(a,EP1(Seg(Seg(b,a,b,a),a,a,x),a,b,x,b),a,
EP1(Seg(Seg(b,a,b,a),a,a,y),a,b,y,b))=a) $\rightarrow$ x=a)

5=δ,α/4   +(Seg(a,EP1(Seg(Seg(b,a,b,a),a,a,c),a,b,c,b),a,
EP1(Seg(Seg(b,a,b,a),a,a,d),a,b,d,b))=a)

6=δ,α/4   -(c=a)

7=R10   +B(a,EP1(Seg(Seg(b,a,b,a),a,a,c),a,b,c,b),Seg(a,
EP1(Seg(Seg(b,a,b,a),a,a,c),a,b,c,b),a,EP1(Seg(Seg(b,a,b,a),a,a,d)a,b,d,b)))

8=5,7   +B(a,EP1(Seg(Seg(b,a,b,a),a,a,c),a,b,c,b),a)

9=R1/8 +(EP1(Seg(Seg(b,a,b,a),a,a,c),a,b,c,b)=a)

10 +B(a,b,Seg(Seg(b,a,b,a),a,a,c))

11 +B(b,b,c)

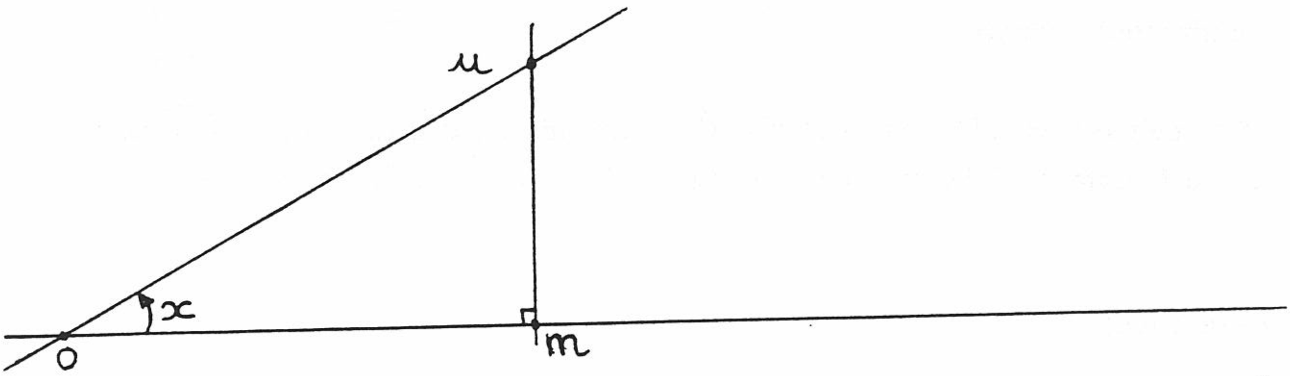
12=R8a' +(a=b) | +B(a,c,EP1(Seg(Seg(b,a,b,a),a,a,c),a,b,c,b))

13=9,12 +B(a,c,a)

14=R1/13 +(a=c)

15=6,14 ⊥

example 3. Our third example is about the trisection of an angle. This operation cannot be done with the ruler and the compass. Nevertheless, a formula which states that any angle can be divided in three equivalent parts can be written in our geometrical language and proved within our tableau system. In other respects, this proof cannot be done without the full schema A13 of elementary continuity. Therefore, algebraic deduction systems based, for example, on Wu's algorithm [2] or refutation based mechanism such as those presented in [3] or [10] are not able to prove it.



Let x be any angle. Its cosinus is well known (being the length of some orthogonal projection of a point onto some line). Let us say that this value is some parameter m (between -1 and +1). The problem is to find an angle y between 0 and x such that the cosinus of 3.y is equal to m. Trigonometrical rules imply that (cos 3.y) is equal to:

$$(\cos y).(4.(\cos y)^2 - 3)$$

Thus, our problem is equivalent to the problem of "geometrically" solving the polynomial equation:

$$m=Y.(4.Y^2-3)$$

Y ranging between m and +1. We will just sketch the proof since it is quite long.

Let $\phi(x)$ be a formula which denotes the fact that x is between m and +1 and that the value of $x.(4.x^2-3)$ is smaller or equal to m. Let $\psi(y)$ be a formula which denotes the fact that y is between m and +1 and that the value of $y.(4.y^2-3)$ is greater or equal to m. Using rules R1,

..., R11 and R12, we can prove that $\vdash_{\mathcal{E}2} \forall$ x y $[\phi(x) \wedge \psi(y) \rightarrow B(m,x,y)]$ (since $\phi(x)$ and $\psi(y)$ only use the notions expressed in the axiom of segment construction and Euclid's axiom). Then, using rule R13, it can be proved that $\vdash_{\mathcal{E}2} \exists$ u $(\forall$ x y $[\phi(x) \wedge \psi(y) \rightarrow B(x,u,y)] \wedge \phi(u) \wedge \psi(u))$, and our polynomial equation is solved.

4. Conclusion.

In this short note, a tableaux style proof procedure has been presented and used to solve classical examples of geometrical theorems. The next and necessary step is to incorporate strategies to the tableaux system and to introduce derived rules, like rules R8a', R8b' and R8c' in section 2, in order to simplify proofs. A first implementation of the tableau method is in progress using the system ATINF [1] and Otter [9]. We think that this approach is very promising, because geometrical constructions can be associated to our tableaux proofs.

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Annex

Tarski's characteristic axioms for elementary geometry are:

A1 [IDENTITY AXIOM FOR BETWEENNESS].
$\forall$ xy $[B(x,y,x) \rightarrow x=y]$

A2 [TRANSITIVITY AXIOM FOR BETWEENNESS].
$\forall$ xyzu $[B(x,y,u) \wedge B(y,z,u) \rightarrow B(x,y,z)]$

A3 [CONNECTIVITY AXIOM FOR BETWEENNESS].
$\forall$ xyzu $[B(x,y,z) \wedge B(x,y,u) \wedge x \neq y \rightarrow B(x,z,u) \vee B(x,u,z)]$

A4 [REFLEXIVITY AXIOM FOR EQUIDISTANCE].
$\forall$ xy $[Eq(x,y,y,x)]$

A5 [IDENTITY AXIOM FOR EQUIDISTANCE].
$\forall$ xyz $[Eq(x,y,z,z) \rightarrow x=y]$

A6 [TRANSITIVITY AXIOM FOR EQUIDISTANCE].

$\forall$ xyzuvw [Eq(x,y,z,u) $\wedge$ Eq(x,y,v,w) $\rightarrow$ Eq(z,u,v,w)]

A7 [PASCH'S AXIOM].

$\forall$ txyzu $\exists$v [B(x,t,u) $\wedge$ B(y,u,z) $\rightarrow$ B(x,v,y) $\wedge$ B(z,t,v)]

A8 [EUCLID'S AXIOM].

$\forall$ txyzu $\exists$vw [B(x,u,t) $\wedge$ B(y,u,z) $\wedge$ x$\neq$u $\rightarrow$ B(x,z,v) $\wedge$ B(x,y,w) $\wedge$ B(v,t,w)]

A9 [FIVE-SEGMENT AXIOM].

$\forall$ xx'yy'zz'uu' [Eq(x,y,x',y') $\wedge$ Eq(y,z,y',z') $\wedge$ Eq(x,u,x',u') $\wedge$ Eq(y,u,y',u') $\wedge$
B(x,y,z) $\wedge$ B(x',y',z') $\wedge$ x$\neq$y $\rightarrow$ Eq(z,u,z',u')]

A10 [AXIOM OF SEGMENT CONSTRUCTION].

$\forall$ xyuv $\exists$z [B(x,y,z) $\wedge$ Eq(y,z,u,v)]

A11 [LOWER DIMENSION AXIOM].

$\exists$xyz [$\neg$B(x,y,z) $\wedge$ $\neg$B(y,z,x) $\wedge$ $\neg$B(z,x,y)]

A12 [UPPER DIMENSION AXIOM].

$\forall$ xyzuv [Eq(x,u,x,v) $\wedge$ Eq(y,u,y,v) $\wedge$ Eq(z,u,z,v) $\wedge$ u$\neq$v $\rightarrow$
B(x,y,z) $\vee$ B(y,z,x) $\vee$ B(z,x,y)]

A13 [ELEMENTARY CONTINUITY AXIOMS]. *All sentences of the form*

$\forall$ vw... {$\exists$z $\forall$ xy [$\phi \wedge \psi \rightarrow$ B(z,x,y)] $\rightarrow$ $\exists$u $\forall$ xy [$\phi \wedge \psi \rightarrow$ B(x,u,y)]}

where ϕ stands for any formula in which the variables x, v, w, ..., but neither y nor z, occur free, ans similarly for ψ, with x and y interchanged.

A Spatial Logic based on Regions and Connection*

David A. Randell, Zhan Cui and Anthony G. Cohn†

Abstract

We describe an interval logic for reasoning about space. The logic simplifies an earlier theory developed by Randell and Cohn, and that of Clarke upon which the former was based. The theory supports a simpler ontology, has fewer defined functions and relations, yet does not suffer in terms of its useful expressiveness. An axiomatisation of the new theory and a comparison with the two original theories is given.

1 Introduction

The use of interval logics for the representation of time are well known in AI research - see for example Allen (1984) and Allen and Hayes (1985) although their development and history extends back much further in philosophical literature, see for example Hamblin (1967, 1971). However, despite the intuitive connection that can be drawn between space and time in terms of such logics, until fairly recently, little work in AI has centred on the development and use of interval logics for space.

We describe an interval logic that can be used to reason about space. The similarity of the title with Clarke's (1981) paper 'A calculus of individuals based on 'connection' ', is not accidental. In Randell and Cohn (1989, 1992) and in Randell (1991) we used Clarke's theory as a foundation to build a theory that supported some basic intuitions about the nature of space, time and processes. Although this theory is formally sound,

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in use, we found some features of both Clarke's theory and our own proved problematic This led to a re-evaluation of the original theory which is presented below.

The structure of the rest of this paper is as follows. In sections 2 and 3, we give a brief overview of the original theory, and point out the various problems we encounterec that led to the development of the revised theory. In section 4 we give the axiomatisec theory, drawing out the contrasts with the original theory. In section 5 we discuss the implications of introducing atomic regions into the theory, and in section 6 we discuss related and further work.

2 Overview of the original spatial theory

The original theory (see Randell and Cohn 1989, 1992 and Randell 1991) is based upor Clarke's (1981, 1985) calculus of individuals based on "connection" and is expressed ir the many sorted logic LLAMA - see Cohn (1987).

The ontological primitives of the theory include physical objects, regions and othe sets of entities. These and other specialisations of these primitive sets of entities are al treated as sorts in the theory and are subsequently embedded in a complete Booleaı lattice, forming a sort hierarchy. However, given the scope of this paper, we shall limi the overview of the original theory to that which applies to space, while reminding th reader that what follows is but a small part of a much larger theory.

The basic part of the theory assumes a primitive dyadic relation: $C(x, y)$ read a 'x connects with y' which is defined on regions; this is axiomatised to be reflexive an symmetric. In terms of points incident in regions, $C(x, y)$ holds when regions x and share a common point. Using the relation $C(x, y)$, a basic set of dyadic relations ar defined. These relations describe differing degrees of connection between regions fror being disconnected, to being externally connected, allowing partial overlap, one regio being a tangential part of the other, or a nontangential part, and so on. All degree of connection from being externally connected to sharing mutual parts and thus bein identical are formally defined.

The theory also supports a set of functions that define the Boolean composition regions, and a set of topological functions that allow for the explicit representation the interior, the closure and the exterior of particular regions. We also extend the bas theory outlined by Clarke by including a further set of dyadic relations that are used t describe regions being either inside, partially inside, or outside another.

The spatial part of the theory represents but a part of a much larger theory, which is now briefly covered. The theory enables the user to describe states, events and processes. For this a set of ternary relations are introduced that enable one to relate pairs of bodies using the dyadic relations mentioned above over time. These are subsequently used to create a set of envisioning axioms in the general theory, which impose constraints upon the manner in which bodies can vary in their degree of connection over time. These form the basis of processes described in the theory, where processes are described in terms of stipulated sequences of direct topological transitions allowed between sets of objects. These processes can either be reasoned about using a direct theorem proving implementation of the theory, or by using a simulation program - see Cui, Cohn and Randell (1992) for further details.

3 Problems

There are several problems that have arisen during our course of research using the original theory. These can be conveniently classified under three distinct, but related headings: conceptual, pragmatic and computational. We shall discuss these in turn.

A common question asked of us concerning the original theory was why we needed to introduce the topological distinctions between the types of regions assumed by the general theory. From the naive point of view, it seemed odd to have open, semi-open and closed regions as a model for regions. This point simply reflects a general concern made by writers in both philosophy and science, that a remoteness exists between the facts of actual observation and the descriptive language used. In Philosophy, this has resulted in a strong interest in developing languages with a clear primitive observational or phenomenal content; languages that can be directly related to the world around us (Hamblin 1971). For example, in terms of content, it seems odd that two regions can be distinct, but that each occupies the same amount of space, as in the case where we take an open region, and its closure.[1] Moreover, given the explicit use of different types of topological regions for describing space, we have the odd result that if a body maps to a closed region of space (which is a natural association), its complement is open, and

[1] A very clear example of this was suggested by Antony Galton, who pointed out that the northern hemisphere, with or without the equator includes the same amount of regional space - the former being a closed region, the latter a semi-open one

that if we consider a body which is broken into two parts, then we have a problem how to split the regions so formed, since any closed interval that is split into two must have a semi-open part, and which is which?[2] From the standpoint of our naive understanding of the world, this topological structure is arguably too rich for our purposes, and in any case appearing in this formal theory, it poses some deep conceptual problems.

Given the choice between two possible theories used for formally representing space, the ease by which a person can understand and use the theory must be taken into account. The basic part of the original theory, concerning regions required the user to be familiar with general topology, both in order to understand the theory, and for any person wishing to extend the theory. We thought this restriction could be eased, but this required a change in the ontology of regions assumed by the original theory, and changes in the extant axiomatisation.

Clarke's (1981, 1985) calculus of individuals is simply presented as an unsorted first order theory, and as such, questions of implementation are understandably not addressed. However, in our case, we had to keep implementational and efficiency questions to the fore. We decided to use a sorted logic, since their effectiveness in reducing the search space for many problems in automated reasoning is well known. Also we wanted to keep our syntax as clear as possible, by absorbing all the monadic predicates in the theory and pushing these into the sortal part of the logic. We originally decided to implement our original theory using Cohn's (1987) sorted logic LLAMA, but this required much groundwork first, since the logic requires the user to first specify the positions of the sorts in the sort hierarchy[3]. This required us to first prove in the sorted theory, for any two potential sorts (being the monadic predicates of the unsorted theory), whether they were disjoint or whether one subsumed the other. This proved to be a particularly difficult and tedious task, which was made especially difficult given the spartan nature of the primitives used in the theory, which meant even basic theorems could prove difficult to tease out. Part of the problem simply lay in the number of potential subsorts, of the sort REGION, we had defined, and again this in part stemmed from the topological basis of the theory stemming from Clarke's theory[4].

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[2]It is interesting to note too that the same difficulties for space also arise in the temporal model, for example, deciding whether the order of intervals should be either ( ], or [ ). See Galton (1990) for further discussion.

[3]However, more recently, LLAMA has been relaxed and only partial sort information need be specified – see Cohn(1992).

[4]By having three kinds of regions (open, closed, semi-open), the number of sorts was immediately

Taking all these factors into account we eventually decided to investigate how the theory could be simplified; this is presented below.

4 The new theory

The new theory, like the original theory, is based upon Clarke's calculus of individuals based on "connection" and again is expressed in the many sorted logic LLAMA. Reasons of space mean that we cannot give full details of the sorted logic assumed below. However, for the purposes of reading this paper, all the reader should bear in mind is that LLAMA allows arbitrary ad hoc polymorphism, and that the variables are not explicitly typed, but that their associated sorts are derived implicitly from their argument positions in specified formulae. We will occasionally highlight certain sortal restrictions; in this case sorts in the theory will be indicated by strings of upper case letters, e.g. REGION, SPATIAL and NULL.

The ontological primitives of the (extended) new theory include physical objects, regions and other sets of entities. These and other specialisations of these primitive sets of entities are all treated as sorts in the theory and are subsequently embedded in a complete Boolean lattice, forming a sort hierarchy. However, here, by restricting ourselves to a theory describing space, we shall only concern ourselves with those sorts that specialise the sort SPATIAL.

Regions in the theory support either a spatial or temporal interpretation. Informally, these regions may be thought to be potentially infinite in number, and any degree of connection between them is allowed in the intended model, from external contact to identity in terms of mutually shared parts.

The basic part of the formalism assumes one primitive dyadic relation: $C(x, y)$ read as 'x connects with y'. For the basic part of the theory, the individuals can be interpreted as either spatial or temporal regions, but as we are describing a theory for space, a spatial interpretation is assumed in the pictorial model we give in Figure 1. The relation $C(x, y)$ is reflexive and symmetric. We can give a topological model to interpret the theory, namely that $C(x, y)$ holds when the topological closures of regions x and y share a common point.[5] Other models also exist. We could simply state that two regions connect,

increased threefold.

[5]In Clarke's theory and in our original theory, when two regions x and y connect, they are said to share a point in common; thus the interpretation of the connects relation in the new theory is weaker.

when it is not possible to 'fit' another distinct region between the two, or alternatively to say when the distance between them is zero. Clarke (1981) only suggests the point based topological interpretation as one possible interpretation for his axiomatisation.

Using $C(x,y)$, a basic set of dyadic relations are defined: '$DC(x,y)$' ('x is disconnected from y'), '$P(x,y)$' ('x is a part of y'), '$PP(x,y)$ ('x is a proper part of y'), '$x = y$' ('x is identical with y'), '$O(x,y)$' ('x overlaps y'), '$DR(x,y)$' ('x is discrete from y') '$PO(x,y)$' ('x partially overlaps y'), '$EC(x,y)$' ('x is externally connected with y)', '$TPP(x,y)$' ('x is a tangential proper part of y') and '$NTPP(x,y)$' ('x is a nontangential proper part of y'). The relations: P,PP,TPP and NTPP being non-symmetrical support inverses (but we omit the definitions below since these are obvious). For the inverses we use the notation Φ^{-1}, where $\Phi \in$ {P,PP,TPP and NTPP}. Of the defined relations, DC,EC,PO,=,TPP,NTPP and the inverses for TPP and NTPP are provably mutually exhaustive and pairwise disjoint. The complete set of relations described above can be embedded in a relational lattice. This is given in Figure 1. The symbol $\top$ is interpreted as tautology and the symbol $\perp$ as contradiction. The ordering of these relations is one of subsumption with the weakest (most general) relations connected directly to top and the strongest (most specific) to bottom. For example, TPP implies PP, and PP implies either TPP or NTPP. A greatest lower bound of bottom indicates that the relations are mutually disjoint, for example with TPP and NTPP, and P and DR. This lattice corresponds to a set of theorems (eg. $\forall xy[PP(x,y) \rightarrow [TPP(x,y) \vee NTPP(x,y)]]$) which we have verified.

$DC(x,y) \equiv_{def} \neg C(x,y)$
$P(x,y) \equiv_{def} \forall z[C(z,x) \rightarrow C(z,y)]$
$PP(x,y) \equiv_{def} P(x,y) \wedge \neg P(y,x)$
$x = y \equiv_{def} P(x,y) \wedge P(y,x)$
$O(x,y) \equiv_{def} \exists z[P(z,x) \wedge P(z,y)]$
$PO(x,y) \equiv_{def} O(x,y) \wedge \neg P(x,y) \wedge \neg P(y,x)$
$DR(x,y) \equiv_{def} \neg O(x,y)$
$TPP(x,y) \equiv_{def} PP(x,y) \wedge \exists z[EC(z,x) \wedge EC(z,y)]$
$EC(x,y) \equiv_{def} C(x,y) \wedge \neg O(x,y)$
$NTPP(x,y) \equiv_{def} PP(x,y) \wedge \neg\exists z[EC(z,x) \wedge EC(z,y)]$

In the original theory, several other defined relations (missing here) were defined. These were the set of relations: '$TP(x,y)$' ('x is a tangential part of y'), '$NTP(x,y)$' ('x

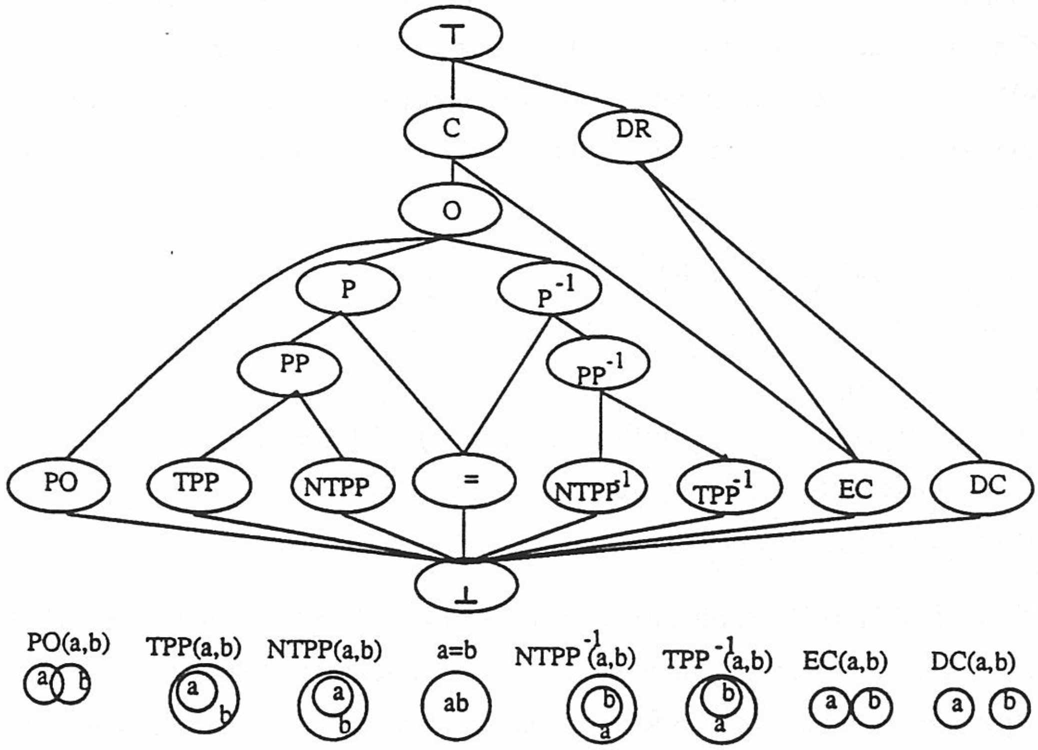

Figure 1: A lattice defining the subsumption hierarchy of the dyadic relations defined solely in terms of the primitive relation $C(x, y)$.

is a nontangential part of y'),'TPI(x, y)' ('x is the identity tangential part of y'), and, 'NTPI(x, y)' ('x is the identity nontangential part of y'). We also omit in the new theory the set of topological functions introduced by Clarke, and adopted by us in the original theory. In this revised theory, we make no formal distinction in our model between open, semi-open and closed regions used to interpret this part of the formalism (as was done in the original theory), so for example now the identity relation does not split into two specialisations here, as it did in the original theory to account for the differences between types of regions. A similar rationale applies for the explicit introduction of the tangential part and nontangential part relations mentioned above - see Randell (1991), Randell and Cohn (1989), Randell and Cohn (1992) for further details.

Excepting the definition for the complement of a region, the Boolean part of the new theory follows the original theory, and Clarke's. The Boolean functions[6] are: 'sum(x, y)' which is read as 'the sum of x and y', 'Us' as 'the universal (spatial) region', 'compl(x)' as 'the complement of x', 'prod(x, y)' as 'the product (i.e. the intersection of x and y' and 'diff(x, y)' as 'the difference of x and y'. The functions: 'compl(x)', 'prod(x, y)' and 'diff(x, y)' are partial but are made total in the sorted logic by simply specifying sorts restrictions and by introducing a new sort called NULL. The sorts NULL and REGION are disjoint.

$$\mathrm{sum}(x,y) =_{def} \iota y[\forall z[\mathrm{C}(z,y) \leftrightarrow [\mathrm{C}(z,x) \vee \mathrm{C}(z,y)]]]$$
$$\mathrm{compl}(x) =_{def} \iota y[\forall z[[\mathrm{C}(z,y) \leftrightarrow \neg\mathrm{NTPP}(z,x)] \wedge [\mathrm{O}(z,y) \leftrightarrow \neg\mathrm{P}(z,x)]]]$$
$$\mathrm{Us} =_{def} \iota y[\forall z[\mathrm{C}(z,y)]]$$
$$\mathrm{prod}(x,y) =_{def} \iota z[\forall u[\mathrm{C}(u,z) \leftrightarrow \exists v[\mathrm{P}(v,x) \wedge \mathrm{P}(v,y) \wedge \mathrm{C}(u,v)]]]$$
$$\mathrm{diff}(x,y) =_{def} \iota w[\forall z[\mathrm{C}(z,w) \leftrightarrow \mathrm{C}(z,\mathrm{prod}(x,\mathrm{compl}(y)))]]$$
$$\forall xy[\mathrm{NULL}(\mathrm{prod}(x,y)) \leftrightarrow \mathrm{DR}(x,y)]$$

In Clarke (1981, 1985) (and also in our original theory) the complement definition is defined so that a region y connects with the complement of region x if and only if y is not a part of x. This has the formal consequence that no region is connected with its own complement.[7] However, this result is not formally derivable in the new theory, and moreover must not be so given the new interpretation. This arises from the new interpretation for the connects relation, since every region (which is not identical to the universal region) will be connected with its own complement. In fact this difference is reflected in the theorem: $\forall x\mathrm{EC}(x, \mathrm{compl}(x))$ which contradicts the related theorem described above.

An additional axiom is then added to the new theory which stipulates that every region has a nontangential proper part:

$$\forall x\exists y[\mathrm{NTPP}(y,x)] \qquad \text{(i)}$$

This axiom mirrors a formal property of Clarkes' theory, where he stipulates that every region has a nontangential part, and thus an interior (remembering that in Clarke's theory a topological interpretation is assumed).

[6] $\alpha(\overline{x}) =_{def} \iota y[\Phi[\alpha(\overline{y})]$ means $\forall\overline{x}[\Phi(\alpha(\overline{x})]]$; thus, e.g., the definition for prod(x, y) is translated out (in the object language) as: $\forall xyz[\mathrm{C}(z,\mathrm{prod}(x,y)) \leftrightarrow \exists w[\mathrm{P}(w,x) \wedge \mathrm{P}(w,y) \wedge \mathrm{C}(z,w)]]$.

[7] Here we are assuming certain restrictions on x. In the unsorted theory assumed by Clarke, this amounts to x not being identical to the universal region - our constant Us.

4.1 Inclusion vs Containment

As with the original theory (but missing in Clarke) a primitive function 'conv(x)' ('the convex-hull of x') is defined and axiomatised.[8]

We use this function to define a set of relations which describe regions being inside, partially inside and outside, e.g. 'INSIDE(x, y)' (x is inside y'), 'P-INSIDE(x, y)' ('x is partially inside y') and 'OUTSIDE(x, y)' ('x is outside y'). This particular set of relations extends below DR(x, y) in the basic theory. The developed theory actually supports many specialisations of these particular relations, with, for example, one region being wholly outside, or just outside, or just inside, or wholly inside another - see Randell and Cohn (1989, 1992) and Randell (1991). However, here we restrict the set of defined relations to the specialisations given above, their inverses, and the set of relations that result from non-empty intersections. The set of base relations for this particular set are finally generated by defining a further set of specialisations of these relations using the EC and DC relations. This finally gives rise to the new set of base relations in the extended theory, which now number 22 instead of 8 in the revised basic theory (cf. 23 and 9 in the original theory).

Two functions capturing the concept of the inside and the outside of a particular region are also definable (where 'inside(x)' is read as 'the inside of x', and 'outside(x)' as 'the outside of x' respectively.

4.2 Geometrically Inside vs Topologically Inside

In the previous section the DR relation was specialised to cover relations describing objects being either inside, partially inside or outside other objects. However this ignores some useful distinctions that can be drawn between different cases of bodies being inside another. In this case we separate out the case where one body is topologically inside another, and where one body is inside another but not topologically inside – this we call being geometrically inside. The important point of one body being topologically inside another is that one has to 'cut' through the surrounding body in order to reach and make contact with the contained body. In the geometrical variant this is not the case (see Figure 2). Thus we can refine INSIDE to TOP-INSIDE and GEO-INSIDE.

[8]Henceforth we omit axioms and definitions for space reasons and refer the reader to Randell, Cui and Cohn (1992b).

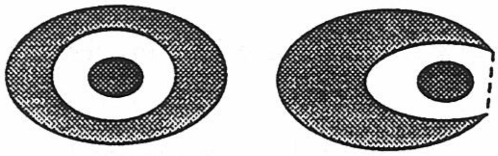

Figure 2: The distinction between being topologically and geometrically inside. The dashed lines appearing here indicate the extent of the convex hull of the surrounding bodies.

4.3 Theorems in the new theory

As mentioned above, some important differences exist between both Clarke's and the original theory, and the new theory. For brevity we shall subsume our original theory under Clarke's, when making the contrast. Where a difference arises between some theorem of Clarke's and our own original theory, we shall make this explicit. First we demonstrate how the topological distinction drawn between open, semi-open and closed regions sanctioned in Clarke's theory cannot be made in the new theory. For Clarke, two regions x and y are identical iff any region connecting with x connects with y and vice-versa, i.e. $\forall xy[x = y \leftrightarrow \forall z[\mathrm{C}(z,x) \leftrightarrow \mathrm{C}(z,y)]]$; however in the new theory, an additional theorem concerning identity becomes provable which is not a theorem in Clarke's theory. This is: $\forall xy[x = y \leftrightarrow \forall z[\mathrm{O}(z,x) \leftrightarrow \mathrm{O}(z,y)]]$. The topological model used in Clarke's theory, together with the absence of boundary elements as regions, explains why this formula is not derivable. For example, given the closure of region x and its interior, then any region overlapping the closure of x, overlaps the interior of x, and vice-versa, (remembering that overlapping regions entail that they share a common interior point) but from this we cannot allow the interior of x to be identical with its closure, which would follow if the related formula were to be a theorem in Clarke's theory.

The next important difference between Clarke's and the new theory is the formula: $\forall xy[\mathrm{PP}(x,y) \rightarrow \exists z[\mathrm{P}(z,y) \wedge \neg \mathrm{O}(z,x)]]$ which is provable in the new theory, but not in Clarke's. Given Clarke's theory supports open, semi-open and closed regions as a model, it becomes clear why this formula is not provable in Clarke's theory, since while the interior of a region is a proper part of its closure, (and boundaries are not regions) there is no other part of the closure which does not overlap the interior. If one adds the condition that the regions in question are closed, then, the formula is true of Clarke's theory, but this condition is waivered in the new theory. Another related formula is: $\forall xy[\mathrm{PO}(x,y) \rightarrow [\exists z[\mathrm{P}(z,y) \wedge \neg \mathrm{O}(z,x)] \wedge \exists w[\mathrm{P}(w,x) \wedge \neg \mathrm{O}(w,y)]]]$, which is a theorem in the new theory but not in Clarke's. A counter example arises in Clarke's theory where we have two semi-open spherical regions, x and y (with identical radii), such that the northern hemisphere of x is open and the southern hemisphere is closed, and the northern hemisphere of y is closed and the southern hemisphere open. If x and y are superimposed so that their centres and equators coincide, then x and y will partially overlap, but no part of x is discrete from y, and vice-versa. Both these theorems in the new theory show that a positive Boolean difference exists between y and x when x is a proper part of y. Again in Clarke's theory this result only follows when both x and y are closed regions.

In the new theory, $\forall x\, \mathrm{EC}(x, \mathrm{compl}(x))$ holds; this contrasts with the theorem: $\forall x\, \mathrm{DC}(x, \mathrm{compl}(x))$ in both the original and in Clarkes' theories. Also here it is worth pointing out that in the original theory (which included Clarke's set of topological operators) we included the axiom: $\forall x \mathrm{EC}(\mathrm{cl}(x), \mathrm{cl}(\mathrm{compl}(x)))$ which ensured that the closure of x externally connected with the closure of the complement of x, where x was restricted so that it was not the universal region.[9]

Other interesting theorems are: $\forall xyz[[\mathrm{C}(z, y) \wedge \neg \mathrm{C}(z, x)] \rightarrow \exists w[\mathrm{P}(w, y) \wedge \neg \mathrm{O}(w, x) \wedge \mathrm{C}(z, w)]]$, and $\forall xy[[\mathrm{PP}(x, y) \wedge \mathrm{Connected}(y)] \rightarrow \exists z[\mathrm{P}(z, y) \wedge \mathrm{EC}(z, x)]]$. Note for the latter formula to be a theorem, an additional restriction on variable y is required, namely that y is a place-holder for a one-piece region.

Readers familiar with either Clarke's theory, or our own original theory may be wondering what happens to the relations TP and NTP which are excluded here. In the new theory, we find that if we defined these relations and added them to the extant set, the two relations would give rise (on the assumption that x is not identical with the universal spatial region) to the theorems: $\forall x \mathrm{TP}(x, x)$ and $\forall x \neg \mathrm{NTP}(x, x)$ respectively. The latter indicates that no positive instance of the relation NTP which is not a case of NTPP can arise in any model of the new theory. Thus we omit NTP and TP for reasons of symmetry and neither relation appears in the relational lattice depicted in Figure 1.

4.4 Comparisons with the Classical Calculus of Individuals

Readers familiar with Leonard and Goodman's (1940) (classical) calculus of individuals will notice similarities between this calculus and the new calculus described above. In

[9]It turns out that if we assume the universal region is topologically connected (which is a definable concept in Clarkes' theory) and that x is not the universal region, we can prove this as a theorem. We are indebted to Laure Vieu who demonstrated the proof to us.

the classical calculus, DR is axiomatised to be irreflexive and symmetrical, and is used to create a set of dyadic relations and Boolean operators defined on individuals. No analogues of DC and EC (defined in Clarke's calculus) are defined in the classical calculus. With the weaker relation C this distinction can be made. The new theory contains, as part of its complement definition, a conjunct that mirrors the definition for complementation in the classical calculus, i.e. the formula: $\forall xy[\mathrm{O}(x, \mathrm{compl}(y)) \leftrightarrow \neg\mathrm{P}(x, y)]$. This conjunct forces the following formula: $\forall xy[\mathrm{P}(x, y) \leftrightarrow \forall z[\mathrm{O}(z, x) \rightarrow \mathrm{O}(z, y)]$ to be a theorem in the new theory; in fact this equivalence mirrors the definition for P in the classical calculus, where P is defined solely in terms of O. The new theory straddles between Clarke's and the classical calculi of individuals.

5 Atomic regions: a discussion

In Randell and Cohn (1989) we defined *atoms* as regions with no proper parts, and an existential axiom was added that ensured every region had an atom as a part. In the intended model, atoms were understood to be 'very small' regions. Atoms were then used in the definition of what we called the skin of a region. This skin is comparable to the notion of a mathematical surface, except that unlike a surface proper, the skin of a region was understood to have non-zero thickness. However, in the new theory without the topological functions, it is surprisingly difficult to define atomic regions without introducing logical inconsistency. In Randell, Cui and Cohn (1992b) we give three potential solutions to the problem posed by admitting atoms into the domain. Two of these require that atoms be introduced as a primitive sort, while the third keeps atoms as a definable sort but introduces points.

6 Related and Further Work

We have already mentioned Clarke's calculus of individuals, our earlier work of which this present theory is a simplification, and Allen's and Hamblin's work on interval logics. The only other work of which we are aware, that uses Clarke's theory for describing space, is Aurnague (1991) and Vieu (1990). Other work on the description of space using a body rather than a point based ontology, can be found in Laguna (1922), Tarski(1956) and Whitehead (1978). There have been some attempts in the qualitative spatial reasoning literature to employ Allen's interval logic, for describing space, see for example Freksa (1990) and Hernandez (1990), but here a stronger primitive relation used, which does not allow the full range of topological relationships to be formally described as given in both Clarkes' and our original and new theories. Apart from the question raised by adding atoms to the theory, we are currently working on the question as to whether the new theory supports decidable subsets. We have already indicated some extensions to this new logic above, including a temporal extension and extending the ontology further to be able to reason about bodies and describe, states, events and processes. For other extensions to the spatial theory itself, work described in Randell (1991) can also be included. For example, we could add a metric extension to the theory, using either a distance function, or alternatively by adding a ternary relation (along the lines of Van Benthem 1982, appendix A) that gives comparative distances between objects.

In Randell, Cui and Cohn (1992b) we also discuss the construction of a transitivity (or composition) table and the necessary 'envisioning axioms' (cf the notion of 'conceptual neighbourhood' in Freksa (1990)) for the revised theory.

7 Conclusions

The new theory gains over Clarke's theory and the original theory we developed from several viewpoints: ontologically (the explicit distinction between open, semi-open and closed regions is eliminated), definitional (there are fewer defined predicates, and fewer axioms), metatheoretically (there are fewer entries in transitivity tables, and fewer nodes in the the sort hierarchy), and computationally (for comparable theorems, there are fewer formulae in the search space, and fewer nested functions to address in definitions).

The major difference at first sight is ontological parsimony, but we argue that the loss of granularity is not important when modelling physical domains, since physical objects correspond to 'closed' regions, and boundaries can be modelled using 'skins'.

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Using Orientation Information for Qualitative Spatial Reasoning

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Abstract. A new approach to representing qualitative spatial knowledge and to spatial reasoning is presented. This approach is motivated by cognitive considerations and is based on relative orientation information about spatial environments. The approach aims at exploiting properties of physical space which surface when the spatial knowledge is structured according to *conceptual neighborhood* of spatial relations. The paper introduces the notion of conceptual neighborhood and its relevance for qualitative temporal reasoning. The extension of the benefits to spatial reasoning is suggested. Several approaches to qualitative spatial reasoning are briefly reviewed. Differences between the temporal and the spatial domain are outlined. A way of transferring a qualitative temporal reasoning method to the spatial domain is proposed. The resulting neighborhood-oriented representation and reasoning approach is presented and illustrated. An example for an application of the approach is discussed.

1 Introduction

Spatial orientation information, specifically: directional information about the environment, is directly available to animals and human beings through perception and is crucial for establishing their spatial location and for wayfinding. Such information typically is imprecise, partial, and subjective. In order to deal with this kind of spatial information we need methods for adequately representing and processing the knowledge involved. This paper presents an approach to representing and processing qualitative orientation information which is motivated by cognitive considerations about the knowledge acquisition process.

1.1 Background

In a study investigating cognitive aspects of temporal reasoning, a new approach to qualitative temporal reasoning was developed [Freksa 1992]. The main feature of this approach was the exploitation of *conceptual neighborhood* between related qualitative relations. The use of this neighborhood information results in several advantages compared with previous approaches, for example: (1) processing incomplete knowledge simplifies (rather than complicates) the computational procedure; (2) uncertainty is easily controlled in the case of fuzzy base knowledge; (3) for an important class of operations, a computationally intractable process becomes tractable.

The obvious question was raised whether the approach originally developed for the one-dimensional directed domain *time* could be advantageously transferred to a more-dimensional and/or undirected domain like 2-D or 3-D *space*. Within the spatial domain, the application of the approach both to subject-centered knowledge, i.e. knowledge available from within the domain, and to external knowledge appeared desirable due to cognitive considerations. The current state of our considerations will be presented in this paper for the 2-dimensional case.

1.2 Qualitative Reasoning

After an initial enthusiasm regarding the potential of high-precision quantitative computation, qualitative reasoning has become increasingly popular in artificial intelligence and its application areas. This is due to a variety of reasons. First of all, it has been recognized that computational quantitative approaches do not always have the nice properties of their analytical counterparts; second, the goal of a reasoning process usually is a qualitative rather than a quantitative result: a decision; third, the input for a reasoning process frequently is qualitative: the result of a comparison rather than a description in quantitative terms; fourth, qualitative knowledge is 'cheaper' than quantitative knowledge since it is less informative, in a certain sense; fifth, qualitative representations tend to be more transparent than their quantitative counterparts; and sixth, humans seem to do qualitative reasoning more easily (and sometimes better) than quantitative reasoning. Thus, we must develop methods for dealing with judgements which are non-quantitative in nature and a quantitative representation of these judgements may not be the best solution.

What do we precisely mean by *qualitative* knowledge? In the context of the present discussion, it may suffice to say that qualitative knowledge is obtained by *comparing* features within the object domain rather than by *measuring* them in terms of some artificial external scale. Thus, qualitative knowledge is relative knowledge where the reference entity is a single value rather than a whole set of categories. For example, if we compare two objects along a one-dimensional criterion, say length, we can come up with three possible qualitative judgements: the first object can be *shorter (<)*, *equal (=)*, or *longer (>)* in comparison with the second object.

From a representation-theoretical point of view, a major difference between the two approaches is that measuring requires an intermediate domain in which the scale is defined while comparisons may be performed directly in the object domain. Dealing with an intermediate domain requires mapping functions between the object domain and the scale domain which may be critical for the reasoning process. Thus, qualitative representations aim at avoiding distortions of knowledge due to intermediate mappings. In addition, reasoning based on qualitative information aims at restricting knowledge processing to that part of the information which is likely to be relevant in the decision process: the information which already makes a difference in the object domain.

1.3 Spatial Reasoning

Physical space and its properties play essential roles in all sorts of actions and decisions. Consequently, the ability to reason in and about space is crucial for systems involved in these actions and decisions. In fact, we can raise the question if formal logic or physical space is more fundamental for reasoning processes: should we view spatial reasoning as a special case of 'general' logic-based reasoning or should we rather view logic-based reasoning as an abstraction (and generalization) of spatial reasoning? From a formal position, these two viewpoints may appear equivalent; however, from a cognitive and computational position, they are not: the logic-based view assumes that spatial reasoning involves special assumptions regarding the properties of space which must be taken into account while the space-based view assumes that abstract (non-spatial) reasoning involves abstraction from spatial constraints which must be treated explicitly.

From a biological point of view, the issue raised above corresponds to the question which ability is more 'primitive' and has evolved first, abstract reasoning or spatial reasoning. If we replace the term 'reasoning' by the less presumptuous term 'dealing', it appears evident that nature has chosen to equip plants and animals first with abilities of dealing with space before abilities of dealing with abstract worlds were developed. Some interesting questions arise in this context: does the ability of dealing with abstract worlds require the ability of dealing with the concrete world or are they two completely independent abilities? Do we have representational, computational, or other advantages when using either abstract or concrete approaches to spatial reasoning – independent of the way nature may have chosen? If there are advantages for the space-based approach, how can the approach materialize?

1.4 Existing Approaches to Qualitative Spatial Reasoning

A variety of approaches to qualitative spatial reasoning has been proposed. Güsgen [1989] adapted Allen's [1983] qualitative temporal reasoning approach to the spatial domain by aggregating multiple dimensions into a Cartesian framework. Güsgen's approach is straightforward but it fails to adequately capture the spatial interrelationships between the individual coordinates. The approach has a severe limitation: only rectangular objects aligned with their Cartesian reference frame can be represented in this scheme.

Chang & Jungert [1986] present a knowledge structure for representing relations between arbitrarily shaped 2-dimensional objects on the basis of string representations. Lee & Hsu [1991] also use string representations and develop a 'picture algebra' for rectangles (or projections of convex shapes] in a 2-dimensional Cartesian framework.

Randell [1991] attacks the problem of representing qualitative relationships of concave objects. He introduces a 'cling film' function for generating convex hulls of concave objects; he then lists all qualitatively different relations between an object containing at most one concavity and a convex object. Egenhofer & Franzosa [1991] develop a formal approach to describing spatial relations between point sets in terms of the intersections of their boundaries and interiors.

Schlieder [1990] develops an approach which is not based on the relation between extended objects or connected point sets. Schlieder investigates the properties of projections from 2-D to 1-D and specifies the requirements for qualitatively reconstructing the 2-dimensional scene from a set of projections yielding partial arrangement information.

Hernández [1990] considers 2-dimensional projections of 3-dimensional spatial scenes. He attempts to overcome some deficiencies of Güsgen's approach by introducing 'projection' and 'orientation' relations. Freksa [1991] suggests a perception-based approach to qualitative spatial reasoning; a major goal of this approach is to find a natural and efficient way for dealing with incomplete and fuzzy knowledge.

Frank [1991] discusses the use of orientation grids ('cardinal directions') for spatial reasoning. The investigated approaches yield approximate results, but the degree of precision is not easily controlled. Mukerjee & Joe [1990] present a truly qualitative approach to higher-dimensional spatial reasoning about oriented objects. Orientation and extension of the objects are used to define their reference frames.

2 Qualitative Orientation

As we have seen, there is a number of different approaches and reference systems for representing spatial knowledge. In order to select an appropriate reference system for a given purpose, the availability of the required information must be taken into account. For example, if we want to represent spatial knowledge as acquired by a person through perception, it does not make sense to use Cartesian coordinates for representing object location since this information is not made available by the perception process.

On the other hand, information about relative spatial orientation in 2-D is available through perception. This information is also available to an external observer of a 2-dimensional spatial scene. Thus, relative orientation information is a good candidate for processing subject-centered or external qualitative spatial knowledge. Therefore we develop a representation scheme in which this kind of information can be directly represented.

2.1 Dimensionality of Space and Domain-Inherent Constraints

In qualitative reasoning, we can relate entities of different dimensionality within a domain of a certain dimensionality. We obtain a relation space whose size depends on the dimensions involved and on constraints inherent in the modelled domain. Consider for example the one-dimensional domain 'length' which is spanned by two 0-dimensional entities (points). Within this 1-dimensional domain we can relate two 0-dimensional entities. The relation space consists of three disjoint classes: 'less', 'equal', and 'greater'.

In the one-dimensional domain we also can relate a 0-dimensional entity to a 1-dimensional entity, e.g. a point x to an interval [a, b]. If we permit $b<a$ and $b=a$, the relation space consists of nine disjoint classes: $x<a, x<b$; $x=a, x<b$; $x>a, x<b$; $x>a, x=b$; $x>a, x>b$; $x=a, x>b$; $x<a, x>b$; $x<a, x=b$; $x=a=b$. Domain-inherent properties may not permit $b<a$ (if the domain is uni-directional) or $b=a$ (if we only

model extended intervals); both restrictions apply to models of temporal events, for example. In this case, the relation space reduces to five relations. Depending on the specific requirements of the modeled domain, we can construct appropriate qualitative relation spaces, in this way.

Directional orientation in 2-dimensional space is a 1-dimensional feature which is determined by an oriented line; an oriented line, in turn, is specified by an ordered set of two points. We will denote an orientation by an (oriented) line *ab* through two points *a* and *b*; *ba* denotes the opposite orientation. Relative orientation in 2-D is given by two oriented lines or two ordered sets of two points. The feature *orientation* is independent of location and vice versa; therefore, the two ordered sets of points can share one point, without loss of generality. Thus, we can describe the orientation of line *bc* relative to the orientation of line *ab*. This corresponds to describing the point location *c* with respect to reference location *b* and reference orientation *ab* (Figure 1a). Note, that if locations *c* and *b* are identical, orientation *bc* is not defined; nevertheless, we can specify the location of *c* wrt. *a* and *b*.

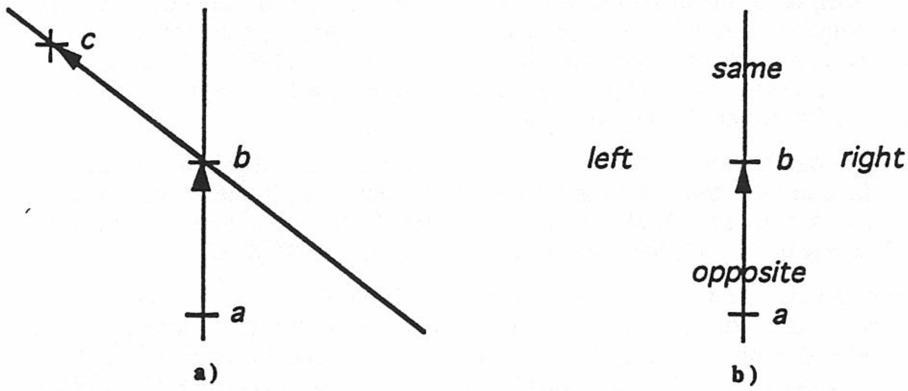

Fig. 1 a) Orientation *bc* relative to orientation *ab*, or: location *c* wrt. location *b* and orientation *ab*; **b)** Orientation relations wrt. location *b* and orientation *ab*.

2.2 Orientation Values and Properties of Qualitative Orientation

The specification of orientation as described in the previous section allows for the distinction of four qualitatively different orientation relations which we have labeled *same, opposite, left, right* (Figure 1b). These relations correspond to point *c* being positioned on line *ab* on the other side of *b* than *a*, on line *ab* on the same side of *b* as *a*, on the left semi-plane of the oriented line *ab*, and on the right semi-plane of the oriented line *ab*, respectively.

Like the qualitative relations *less, equal, greater*, the orientation relation *same* is transitive. The relation *opposite* is periodic in the sense that its repetitive application results in a periodic pattern of resulting orientations, e.g. *opposite* ∞ *left* yields *right*, *opposite* ∞ *opposite* ∞ *left* yields *left*, *opposite* ∞ *opposite* ∞ *opposite* ∞ *left* yields *right*, etc. The qualitative relations *left* and *right* are not periodic, in general; they subsume a wide spectrum of possible quantitative orientations.

Unlike in the case of linear dimensions, incrementing quantitative orientation leads back to previous orientations. In this sense, orientation is a circular dimension. Existing approaches do not deal with periodicity of orientation explicitly. Periodicity is either eliminated by not admitting certain orientations as in [Schätz 1990] or it is ignored by treating different orientations as independent entities as in Frank [1991].

2.3 Augmenting Qualitative Orientation Relations

We can augment the number of orientation relations by introducing additional decision criteria. From a geometrical point of view, the segmentation of 2-dimensional space into two semi-planes perpendicular to the reference orientation *ab* comes to mind immediately. A front/back segmentation already became visible in the *same / opposite* distinction of orientations.

Although people and most animals do not have a perception system for explicit front/back or forward/backward discrimination as they do for left/right discrimination, the segmentation of the plane into a front and a back semi-plane also is meaningful from a cognitive point of view: we conceptualize people, animals, robots, houses, etc. as having an 'intrinsic front side' (compare Pribbenow [1990], Mukerjee & Joe [1990]); this results in an implicit dichotomy between a front region and a back region and a forward and backward orientation.

Introducing the front/back dichotomy results in a substantial gain of information: in combination with the left/right dichotomy we obtain eight meaningful disjoint orientation relations, namely *straight-front (0), right-front (1), right-neutral (2), right-back (3), straight-back (4), left-back (5), left-neutral (6),* and *left-front (7).*

From the viewpoint of a tradition predominantly employing quantitative descriptions it may appear confusing that categories with rather unequal scope are used on the same level of description: the relations *right-front, right-back, left-back,* and *left-front* correspond to an infinite number of angles while *straight-front, neutral-right, straight-back,* and *neutral-left* correspond to a single angle. For qualitative reasoning, however, only distinguishable features count – and most angles cannot be distinguished, in our setting. Note that the orientation relations represent comparative, i.e qualitative values; they do not require a fixed reference system or cardinal directions.

At this point it may be interesting to note the correspondence between orientation and movement. If we view points *a, b,* and *c* as a chain of positions traversed in sequence, then the orientations correspond to the directions of movement while 'undefined orientation' *(c=b)* corresponds to 'no movement'. The correspondence between orientation and movement is particularly visible in natural language words like *forward* and *backward.*

The arrangement depicted in Figure 1a suggests four ways in which the *front/back* dichotomy can be applied: (1) perpendicular to *ab* in *a*, (2) perpendicular to *ab* in *b*, (3) perpendicular to *bc* in *b*, (4) perpendicular to *bc* in *c*. Eventually we will use all four dichotomies in order to increase the 'qualitative resolution' in spatial reasoning. But we will proceed in stages, in order to make the approach more transparent.

Consider orientation *ab* with a front/back dichotomy introduced in *b* (Figure 2a). We can distinguish eight regions, each corresponding to one qualitative orientation (labeled 0 - 7) and the location *b* corresponding to no orientation. We can do the same for orientation *ba* with a front/back dichotomy introduced in *a*. The result is depicted in Figure 2b.

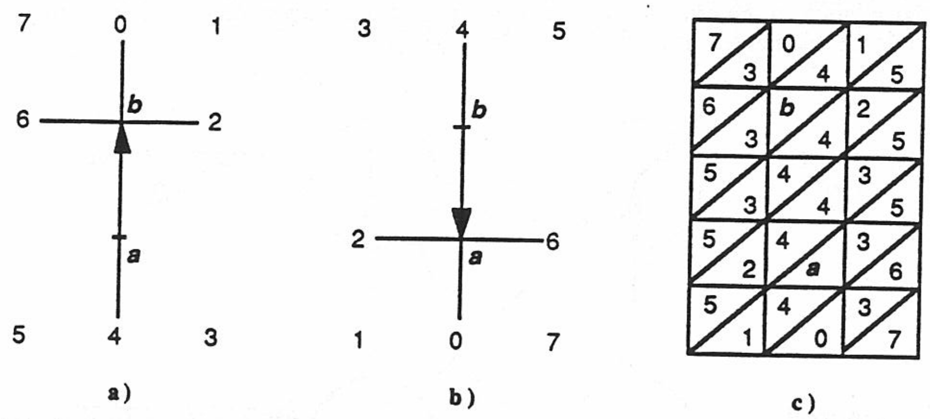

Fig. 2 Combination of left/right and front/back dichotomies into a system of orientations; a) front/back dichotomy wrt. *ab* in *b*; b) front/back dichotomy wrt. *ba* in *a*; c) matrix of combined orientation labels for the 15 qualitative locations.

Figure 2c merges the labels of Figures 2a and 2b into a matrix which distinguishes 15 regions. Each of the regions corresponds to an orientation wrt. *b* (designated in the upper left of the corresponding matrix field) and/or wrt. *a* (designated in the lower right of the corresponding matrix field). The matrix in Figure 2c permits the qualitative description of any location *c* wrt. location *b* and orientation *ab* and wrt. location *a* and orientation *ba*.

The orientation-based qualitative location relation is slightly more general than the qualitative orientation relation since it includes the orientation-less case $c=b$ resp. $c=a$. Therefore we will use it in the following. We will use the same relation labels for denoting qualitative locations as for the corresponding locations; we will denote the orientation-less location by the reference point it corresponds to or by the symbol *i* (identical location).

3 Conceptual Neighborhood and Spatial Knowledge

Freksa [1992] shows for the one-dimensional case of temporal knowledge that there are considerable cognitive and computational advantages to arranging knowledge according to an appropriate *conceptual neighborhood* relation. The conceptual neighborhood principle can be applied to spatial knowledge equally well.

3.1 Conceptual Neighborhood of Spatial Relations

Two relations in a representation are conceptual neighbors, when an operation *in the represented domain* can result in a direct transition from one relation to the other. In physical space, operations can be movements in space or spatial deformations. For example, the relations *left-front (7)* and *left-neutral (6)* and *identical location (i)* are conceptual neighbors by pairs (Figure 3). In contrast, the relations *left-neutral* and *straight-front* are not conceptual neighbors, since any physical operation from one spatial relation to the other would result in at least one intermediate relation – for example the relation *left-front* or *identical location*.

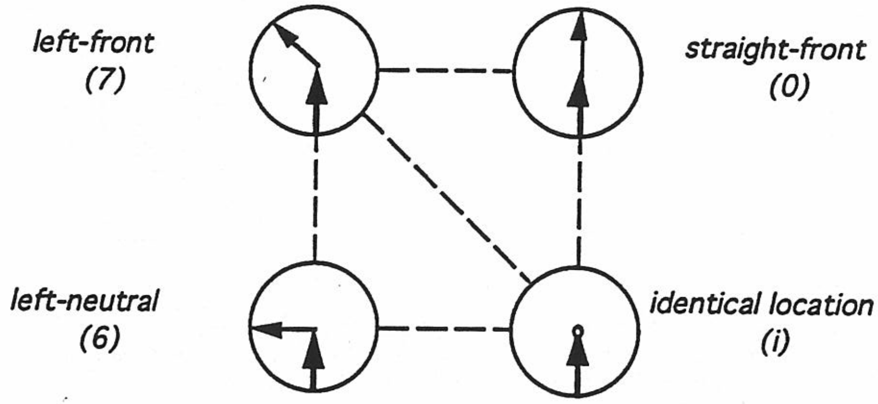

Fig. 3. Relations *7* and *0*, *0* and *i*, *i* and *6*, *6* and *7*, *7* and *i* are conceptual neighbors; relations *6 and 0* are not.

What happens to conceptual neighborhood when we introduce additional differentiations as in Figure 2c? By introducing the second front/back dichotomy through point *a*, we effectively split up the relations *3*, *4*, and *5* into three finer relations each, namely *(3/5, 3/6, 3/7)*, *(4/4, 4/a, 4/0)*, and *(5/3, 5/2, 5/1)*. The coarser original relation becomes a neighborhood of finer relations. Some of the finer relations within a neighborhood are neighbors, some are not. For example, *3/5* and *3/6*, *3/6* and *3/7* are conceptual neighbors, but *3/5* and *3/7* are not.

Note that the finer relations do not resolve the orientation information more finely, although they are defined purely in terms of qualitative orientations. Rather, they distinguish between different qualitative distances. This is shown in Figure 4.

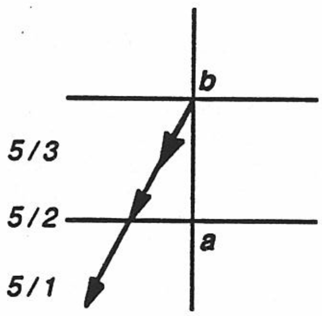

Fig. 4. The combination of orientations wrt. different reference points yields qualitative distance information.

There are also conceptual neighbor relations between fine relations from different neighborhoods, provided that these neighborhoods themselves are neighbors. For example, *3/5* and *4/4* are conceptual neighbors, but *3/5* and *5/3* are not. Figure 5 depicts the conceptual neighbor relations for all 15 location relations. The 15 qualitative relations form 105 (unordered) pairs. 30 of these pairs have the conceptual neighborhood property.

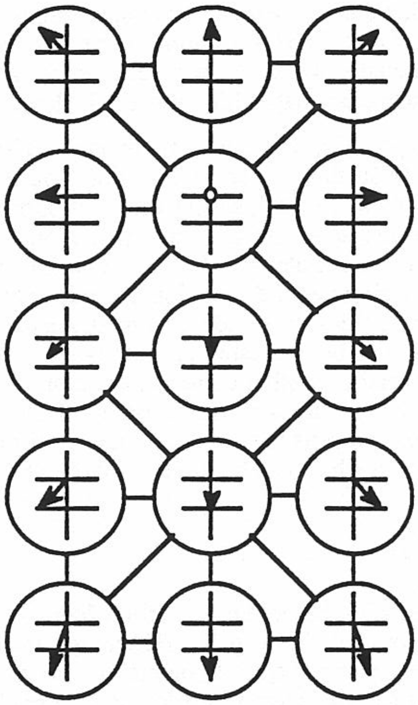

Fig. 5. The 15 qualitative orientation and location relations arranged by conceptual neighborhood. The symbol ‡ depicts iconically line *ab* with the intersections at *a* and at *b*. The arrow depicts the orientation of *bc*.

Conceptual neighborhood structures are important since they intrinsically reflect the structure of the represented world with their operations. Such representations of properties of the represented domain [Furbach et al. 1985] allow us to implement reasoning strategies which are strongly biased towards the operations in the represented domain. They can be viewed as procedural models of this domain. In the case of representing the spatial domain, conceptual neighborhoods contribute to the implementation of imagery processes. From a computational point of view they have the advantage of restricting the problem space in such a way that only operations will be considered which are feasible in the specific domain.

3.2 What are Appropriate Entities to be Spatially Related?

Models of spatial knowledge can either represent abstract point objects or spatially extended objects. Most approaches to representing qualitative spatial knowledge consider the relation between spatially extended objects, or formally speaking between (3-D) volumes, (2-D) areas, or (1-D) intervals. While this approach appears natural, at first glance, considerable drawbacks become apparent upon closer consideration. The main problem is that there is a multitude of possible classes of shapes which cannot be handled equally well. As a consequence, some approaches are restricted to convex or to rectangular shapes [Güsgen 1989, Hernández 1990].

Our representation uses point locations as basic entities. There are several motivations for this approach. First, the properties of points and their spatial relations hold for the entire spatial domain. Second, shapes can be described in terms of points at various levels of abstraction and with arbitrary precision – or can be ignored. Third, it appears desirable to be flexible wrt. the spatial entities and their resolution: in some contexts, we view objects as 0-dimensional spatial points (e.g. position of stars under the sky, position of cities on a wide-area map, position of land marks in a town); in other contexts we may be interested in their 1-dimensional extension (e.g. width of a river, length of a road); in other contexts, a 2-dimensional projection may be of interest (e.g. area of a lake); and sometimes the full 3-dimensional shape of an object or a 3-D constellation of objects is of interest. Our goal has been the development of a fundamental approach which can be used in a large variety of situations.

4 Qualitative Spatial Reasoning

After presenting an orientation-based representation framework we now illustrate how to use this framework for qualitative spatial reasoning. Initially, the conceptual neighborhood structure of the orientation relations mainly serves to help visualize the structure, the operations, and the regularity of the domain and to clarify the approach.

4.1 Orientation-Based Inferences

The representation developed in the foregoing sections enables us to describe one spatial vector with reference to another spatial vector. In analogy to the inference scheme for relating one temporal interval to another temporal interval described by Allen [1983], we develop here an inference scheme for orientation-based spatial inferences.

We will denote the segment between ***a*** and ***b*** of the oriented line ***ab*** as vector ***ab***. Suppose, we know the qualitative spatial relation of vector ***bc*** to vector ***ab*** and the relation of vector ***cd*** to vector ***bc***. We would like to infer the relation of vector ***bd*** to the original reference vector ***ab***.

We will first illustrate the simple case of a single front/back dichotomy, i.e., we consider eight orientation relations for ***bc*** and for ***cd***. The result of the inference is to be expressed in terms of the same eight relations. The front/back dichotomy divides both *ab* and *bc* in point *b*. For reasons of uniformity, we will relate *d* to *cb* instead of *bc;* the front/back dichotomy then is always at the front of the vector (compare Figure 6a). We use the notation (labels *0* through *7*) to denote orientations as introduced in Figure 2.

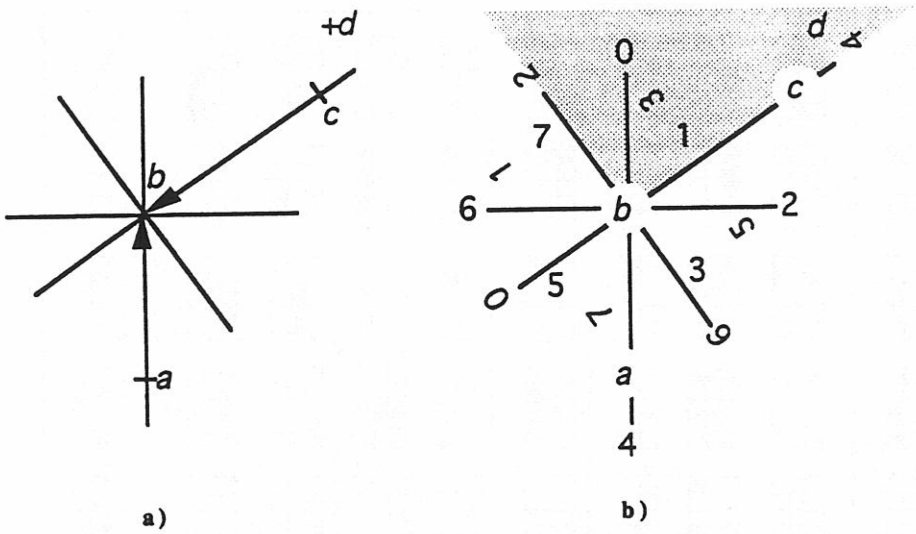

Fig. 6 a) *a, b,* **and** *c* **define two left/right and front/back dichotomies in** *b* **for describing** *d;* **b) Each pair of dichotomies defines eight orientations;** *d* **is located in the shaded area.**

Take a simple example: Let *c* ***right-front (1) ab*** and *d* ***left-front (7) bc*** (Figure 6a). We do not have a front/back dichotomy of *bc* in point *c;* thus, we cannot represent "*d left-front (7) bc*". We use "*d right-back (3) cb*", instead. This relation describes a more general case, since it also includes part of the region ***left-back bc*** (Figure 6b). Informally speaking, we can infer that ***bd*** is ahead of ***ab***; we cannot infer whether *d* is located in the left, straight, or right front region of ***ab***. More formally, we infer: ***bd left-front (7) ab*** or ***bd straight (0) ab*** or ***bd right-front (1) ab***.

Figure 7 depicts the composition table for the 8*8 orientation relations. Each table entry corresponds to an orientation and/or location relation as suggested by Figure 5. The location of *a* and *b* in the icons of the column of initial conditions and in the table is indicated in the top icon of the column of initial conditions; the location of *b* and *c* in the icons of the row of initial conditions is indicated in its leftmost icon. In the column of initial conditions, black squares mark the possible location of *c;* in the row of initial conditions and in the table, black squares mark the possible locations of *d.* The bottom row and the rightmost column display location inferences for the orientation-less cases (*c=b* and *d=b*, respectively).

The composition table forms the basis for qualitative orientation-based reasoning. The table is arranged in such a way that neighboring rows and columns always correspond to conceptually neighboring initial conditions for the inference. Of course, not all conceptually neighboring relations can be depicted by neighboring rows and columns in a 2-dimensional table. Note that with this arrangement, spatially neighboring table entries (corresponding to the inferences) also are conceptual neighbors.

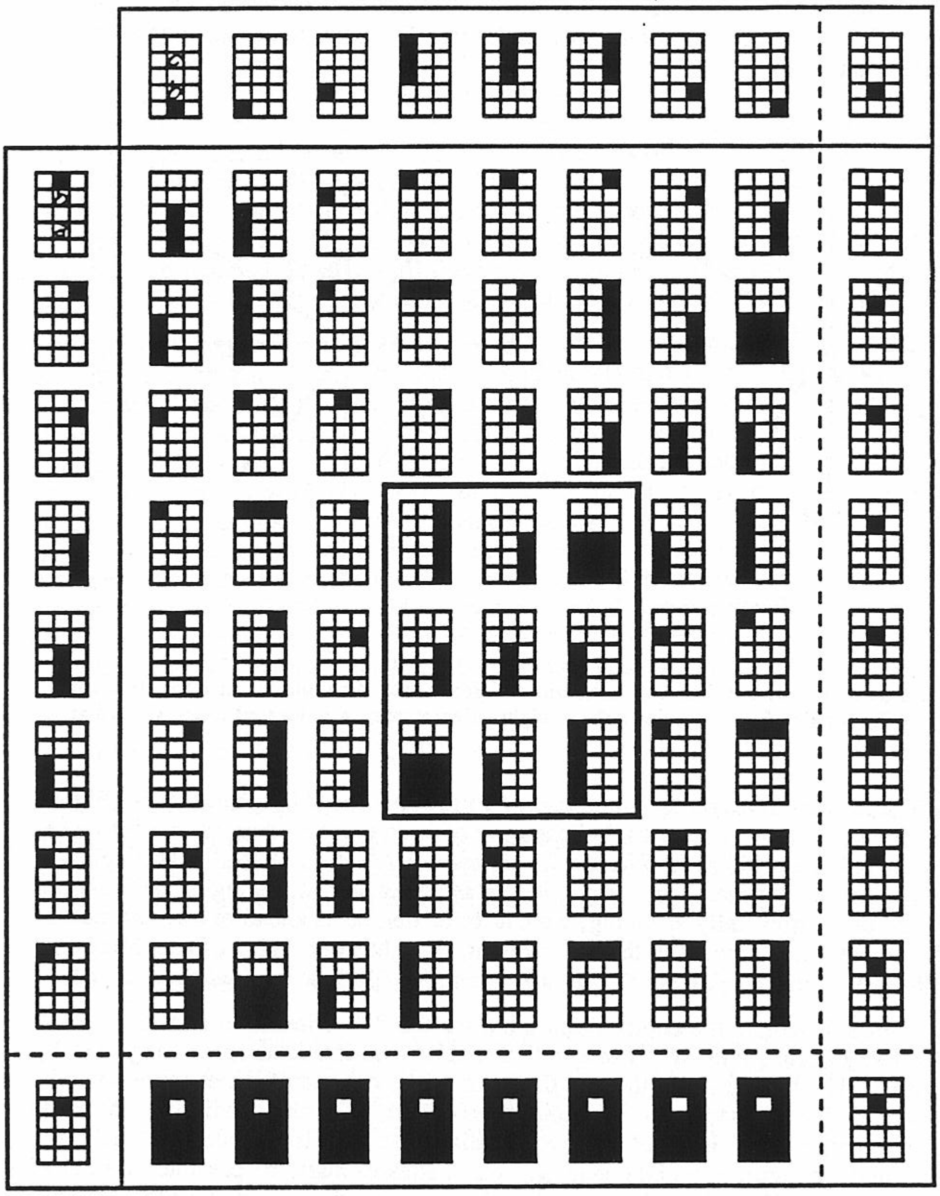

Fig. 7. Iconic composition table for nine location/orientation relations.

The entries in the composition table for the orientations follow a simple formation rule. Let r denote the orientation of c wrt. ab and s the orientation of d wrt. bc. The resulting orientation t wrt. ab then is:

$$t = \left\{ \begin{array}{ll} r+s & \text{for } r \text{ or } s \text{ even} \\ (r+s-1) \ldots (r+s+1) & \text{for } r \text{ and } s \text{ odd} \end{array} \right\} \bmod 8$$

where $(r+s-1) \ldots (r+s+1)$ denotes a range of possible orientations.

Although in one fourth of the cases there is some uncertainty as to which specific qualitative orientation holds – in these cases there is a range of three neighboring possibilities which effectively increase the range of possible angles from 0° or 90° to 180° – we always have certainty about the resulting uncertainty. This is very important, since in certain situations the precision of the result may matter, in others it may not.

Note that the composition table would look more symmetrical if we merged the three lower rows of the icons into one (without loss of information). The expanded graphical notation is used for consistency with the representation for reasoning with higher resolution.

The conclusions obtained through the reasoning procedure can be used for further inferences. Not all conclusion patterns, however, can be found in the composition tables; some conclusions correspond to disjunctions of initial conditions. Accordingly, correct inferences for those patterns are found by forming the logical disjunction of the corresponding compositions. This operation can be visually carried out by superimposing the corresponding icons in our pictorial notation. Alternatively, the composition table could be expanded to explicitly include the complex cases or the conceptual neighborhoods could be exploited for a coarse reasoning approach. These techniques are discussed in detail in Freksa [1992].

4.2 Higher Resolution Reasoning

The reasoning procedure presented in the foregoing section was based on the left/right dichotomy and a single front/back dichotomy for each oriented entity. In this section, we will illustrate how the inferences can be refined by making use of the second front/back dichotomy introduced in section 2.3. This dichotomy corresponds to splitting up rows 4 to 6 of the composition table into three sub-rows each and columns 4 to 6 into three sub-columns each. At the intersection of these rows and columns (marked in Figure 7) we now can make more precise inferences, i.e, we can restrict the range of possible orientations (or locations) of d wrt. ab. The result is depicted in Figure 8.

Inferences also can be refined by processing evidence from multiple sources with the same composition table and combining the results. For example, from *c right-front (1) ab* and *d left-back (5) cb* follows *d right (1, 2, 3) ab*. From *c' right-front (1) ba* and *d left-front (7) bc'* follows *d front (7, 0, 1) ba*. If both descriptions of d hold, their conjunction also holds; thus *d left-front ba*. The inference chain is depicted in Figure 9.

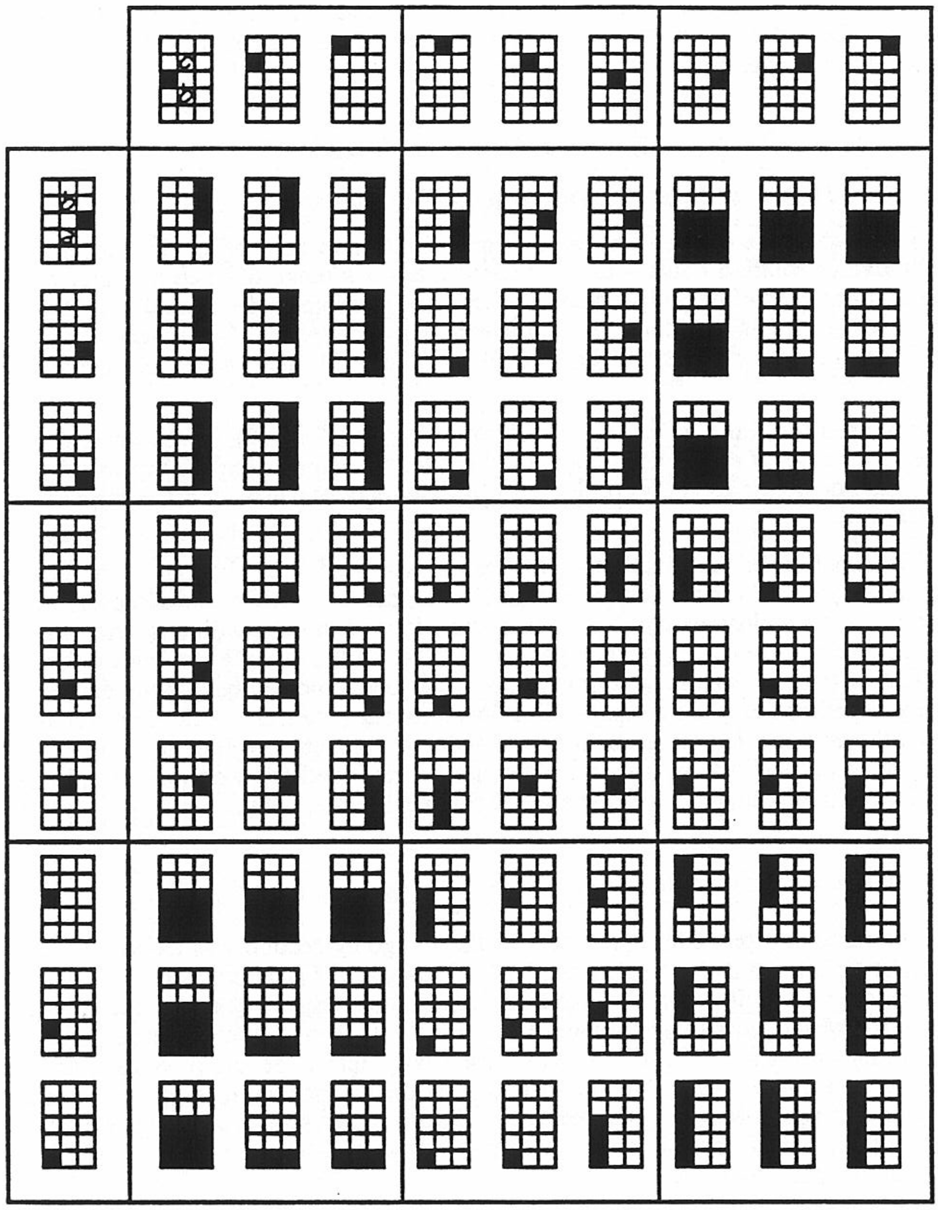

Fig. 8. Fine grain composition table for the marked region in Figure 7.

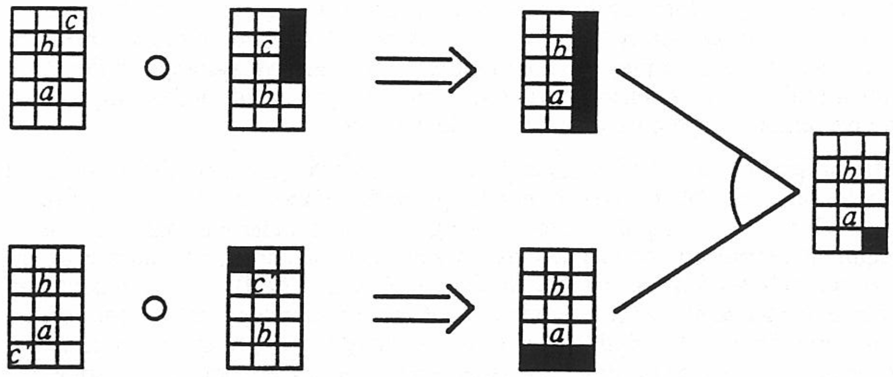

Fig. 9. Refining an inference through multiple evidence.

4.3 Applications

A simple example for an application of orientation-based qualitative spatial reasoning is the process of determining a location in space on the basis of our own location and another location we know. Suppose, we walk from start location *a* to location *c* and we have reached the intermediate location *b*. We can describe orientation and distance of location *c* qualitatively with reference to vector ***ab***, i.e, we compare the road segment ***bc*** to the road segment ***ab*** with respect to their orientation. At position *c*, we can compare the next road segment ***cd*** with the previous stretch, the section ***bc***. The inference step then determines the goal location *d* with respect to the initial road segment ***ab***.

Such an inference can be relevant for a wayfinding process. Suppose, we have a route description from a known location to an as yet unknown place in terms of orientation information (left, straight, right; forward, neutral, backward). We would like to determine the location of the unknown place and the direct route to this place. The described approach can perform this task in qualitative terms, i.e., it can specify a region in which the place can be found.

Suppose, we have two different route descriptions – for example our own description and that of another person. The approach allows us to determine if both routes may lead to the same place; this is the case when the regions described by the inference have a non-empty intersection. Conversely, if we know that both routes in fact lead to the same place, it may be possible to derive a more precise description of the location of this place.

5 Discussion

The approach outlined in this paper is motivated by considerations about spatial knowledge of cognitive systems. More specifically, it is based on the insight that spatial knowledge of natural cognitive systems tends to be qualitative rather than quantitative in nature. The qualitative approach is particularly useful for identification tasks, e.g. for object location tasks, which represent a large fraction of cognitive activity. Furthermore, directional orientation is easily available through perception processes and appears to play an important role for cognitive systems, as the more general meaning of *orientation* suggests. Thus, the presented method applies the qualitative reasoning approach to orientation knowledge.

The present paper only discusses the basic approach. The neighborhood-based approach also is suitable for coarse reasoning, another important ability of cognitive systems. Coarse reasoning allows for drawing inferences under uncertainty and does not require the evaluation of disjunctions, provided that the uncertainty range is a conceptual neighborhood of alternatives (compare Freksa [1992]). The approach can easily be extended to allow for a certain kind of fuzzy reasoning: for an identification task, we may have a description which may or may not apply in the strict sense; when we can not identify the described object by means of the strict interpretation, the neighborhood structure provides information for relaxing the interpretation in an appropriate way. Neighborhood-based reasoning also has computational advantages, specifically for processing perception-based knowledge. For the case of orientation-based reasoning, however, specific analyses have not yet been carried out.

We have discussed in this paper only one of a set of possible spatial inferences one might want to draw: from $c\,R_1\,ab$ and $d\,R_2\,bc$ we inferred $d\,R_3\,ab$. This inference pattern requires a particular sequence of input relations for reasoning through a chain of inference steps. For certain applications, the input knowledge and/or the desired inference may require a different inference pattern. For example, we may want to infer $d\,R_4\,ac$, $b\,R_5\,ac$, $b\,R_6\,ad$, etc. instead. Such inferences require new composition tables which share important properties with the one discussed here. Other variations are conceivable and should be explored.

Acknowledgements

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Utilizing Interval-Based Event Representations for Incremental High-Level Scene Analysis

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Abstract

Within the project VITRA (VIsual TRAnslator) we are concerned with the design and construction of integrated knowledge-based systems capable of translating visual information into natural language descriptions. In this contribution[1] the focus will be on high-level scene analysis, i.e., the step from a geometrical representation, as it might be provided by a vision component, into conceptual descriptions of object motions. In a combined vision and natural language system aiming at simultaneous natural language descriptions of dynamic imagery the recognition of such motion events has to be done incrementally in order to be able to talk about events even while they are progressing. We present course diagrams as a means for such an incremental motion analysis and show how they can be constructed automatically from interval-based event representations using temporal constraint propagation techniques.

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1 Introduction

Image understanding and natural language processing are two major areas of research within AI that have generally been studied independently of one another. Collaborating with the vision group at the Fraunhofer-Institut (IITB, Karlsruhe), the project VITRA (VIsual TRAnslator) is concerned with the combination of natural language and vision. Different domains of discourse and communicative situations are examined in order to design an interface between image understanding and natural language systems.

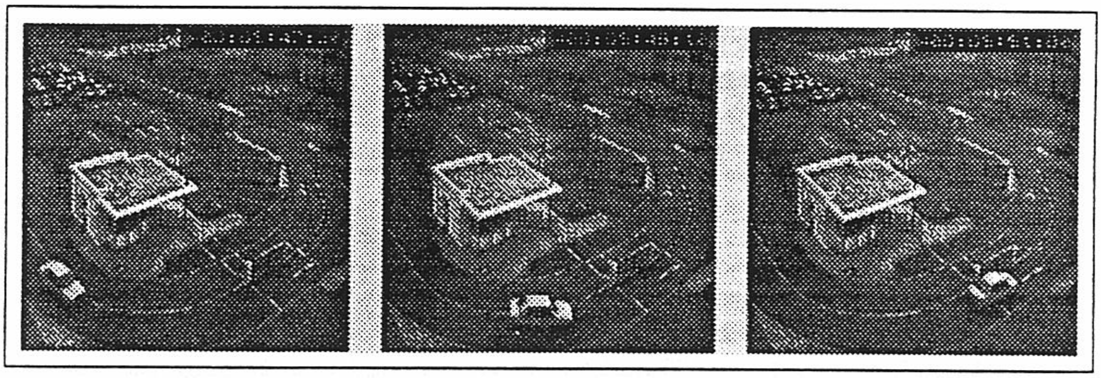

Figure 1: A short traffic scene

The following scenarios are under investigation:

- Answering questions about observations in traffic scenes (c.f. [Schirra et al. 87])
- Generating running reports for short sections of soccer games (c.f. [André et al. 88]).
- Describing routes based on a 3-dimensional model of the Saarbrücker University Campus (c.f. [Herzog et al. 92])
- Communicating with an autonomous mobile robot (*planned*)

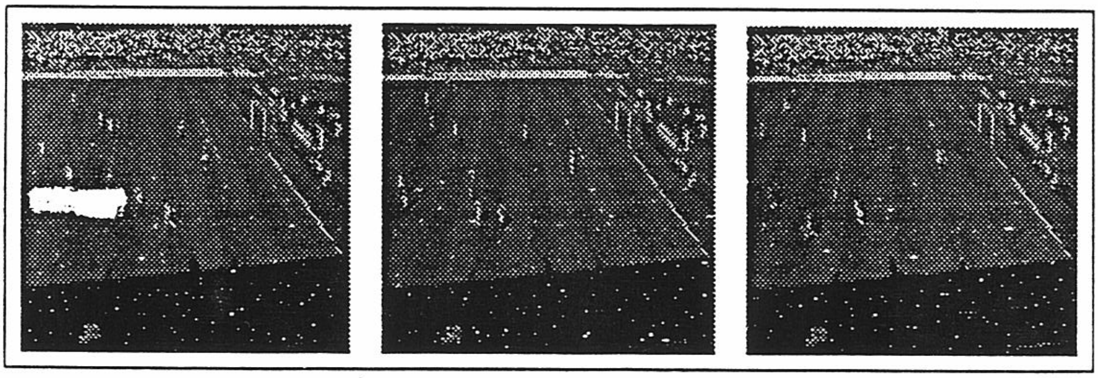

Figure 2: Three frames from the Soccer domain

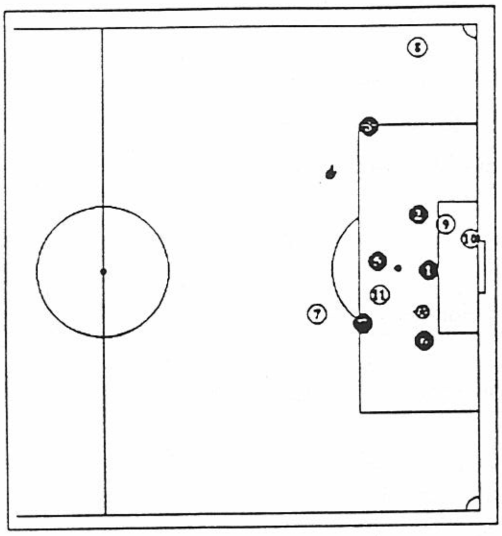

Figure 3: 2D Representation

The results already obtained in connecting a vision component and a natural language access system have been limited to a bird's eye view and thus 2-dimensional representation of the scenes under discussion. Within the new VITRA system the methods developed so far will be extended in order to cope with 3-dimensional geometric representations (c.f. [Herzog 92], [Wazinski & Herzog 92]). Advances in low-level vision, as it is carried out by our project partners, form a promising basis for this kind of extensions. The system XTRACK (c.f. [Koller 92], [Koller et al. 92]) allows for the automatic model-based recognition, tracking, and classification of vehicles in traffic scenes. Research described in [Rohr 89] and [Rohr & Nagel 90] concentrates on the model-based 3D-reconstruction of *non-rigid* bodies. The geometric model utilized there for the recognition of pedestrians is already integrated into the VITRA system in order to represent the players in the Soccer domain. Figure 1 and 2 show some frames taken from real world image sequences, that have been investigated. The previous 2-dimensional geometrical model, with players only represented as centroids, is visualized in figure 3. The images in figure 4 have been generated from our internal 3-dimensional models.

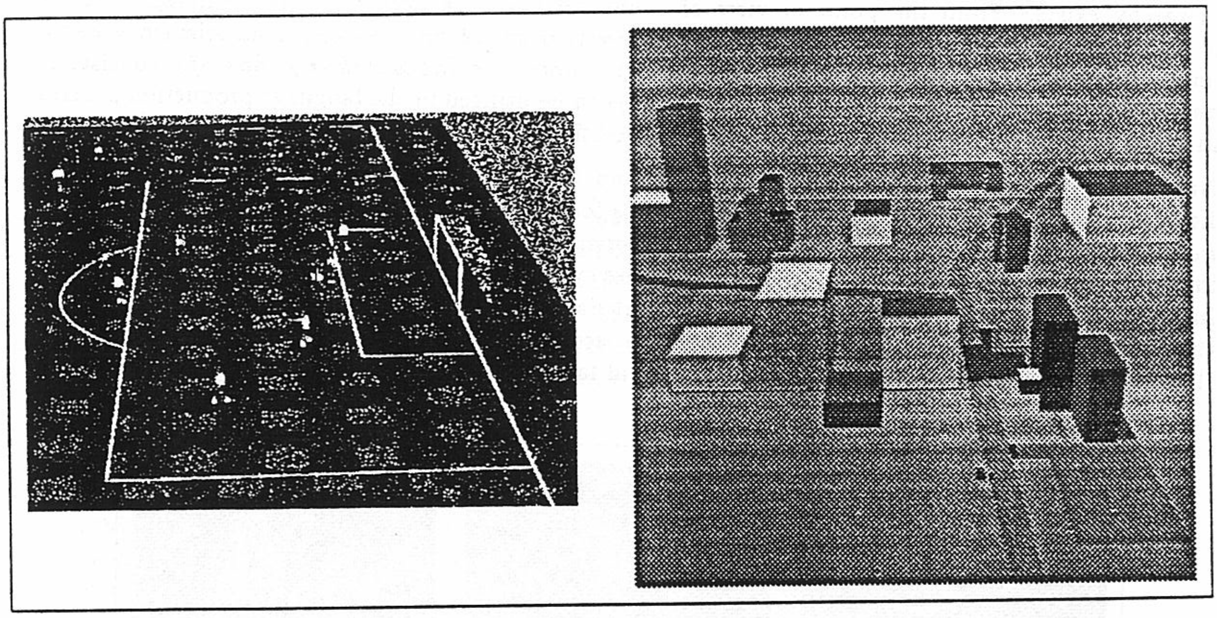

Figure 4: Synthesized images

2 High-Level Scene Analysis

The interpretation of object motions in terms of natural-language-oriented concepts constitutes a central step in the process of translating the results of low-level vision processes into a natural language description. Different approaches for such a high-level scene analysis have been proposed:

Badler: Interpretation of simple object motions in wire-frame image sequences (c.f. [Badler 75])

SUPP: Feature-based verb selection for picture patterns (c.f. [Okada 79])

ALVEN: Interpretation of left ventricular heart motion (c.f. [Tsotsos 85])

HAM-ANS: Natural language dialog about object motions in a traffic scene (c.f. [Hoeppner et al. 83])

NAOS: Retrospective natural language description of object movements in a traffic scene (c.f. [Neumann 89], [Novak 87])

SOCCER: Simultaneous natural language description of short sections from soccer games (c.f. [André et al. 88])

EPEX: Database-assisted extraction of complex motion events in a traffic scene (c.f. [Walter 89])

Karlsruhe Motion Analysis System: Incremental feature-based computation of motion events in a traffic scene (c.f. [Heinze et al. 91], [Kollnig 92])

In ALVEN, HAM-ANS, NAOS, EPEX, as well as in our own system, the recognition of movements is based on a hierarchy of event models, i.e., declarative descriptions of classes of higher conceptual units capturing the spatio-temporal aspects of object motions. Fixed sets of semantic features are employed instead in SUPP and the KARLSRUHE system. Since the motion concepts are only defined in terms of the features they are semantically independent from each other and thus no abstraction hierarchy exists. From the point of view of a natural language access system, semantic features alone do not impose enough structure on the represented knowledge. A conceptual hierarchy based on specialization (e.g. **walking is a moving**) and temporal decomposition (e.g. **passing** consists of **swing-out**, **drive-beside**, and **swing-into-line**) can be utilized in the language production process in order to guide the selection of the relevant propositions (c.f. [Novak 87], [André et al. 88]).

Natural language access systems like HAM-ANS and NAOS concentrate on an *a posteriori* analysis. Low level vision considers the entire image sequence for the recognition and cueing of moving objects; motion analysis, i.e. event recognition, happens afterwards, based on complete trajectories. Since only information about a past scene can be provided, these systems generate *retrospective* scene descriptions. In VITRA we favour an *incremental analysis*. Input data is supplied and processed simultaneously as the scene progresses. Information about the present scene is provided and immediate system reactions (like motor actions of a robot, *simultaneous* natural language utterances) are possible.

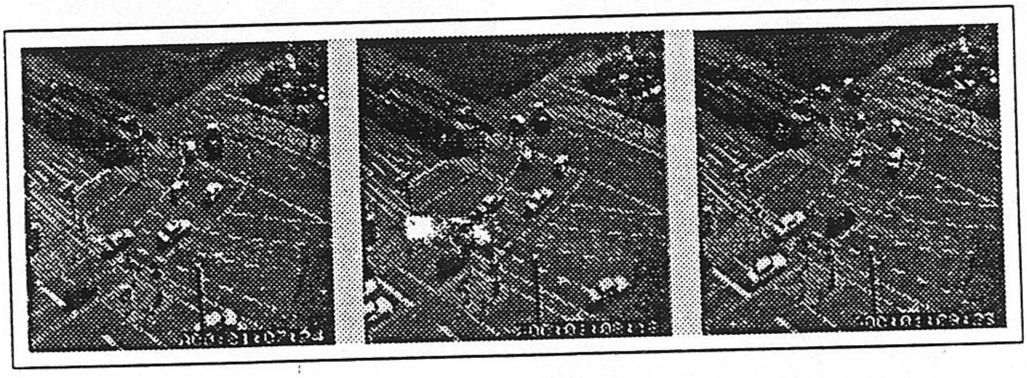

Figure 5: A "passing" event in a traffic scene

3 Incremental Event Recognition

If a real-world image sequence is to be described simultaneously as it is perceived, one has to talk about events even while they are currently happening and not yet completed. Thus events have to be recognized stepwise as they progress and event instances must be made availlable for further processing from the moment they are first noticed. Consider the examples given in figure 5, where a white station wagon is passing a pick-up truck, and in figure 2, where a player is transfering the ball to a teammate.

Since the distinction between events that have and those that have not occured is insufficient, we have introduced the additional event predicates **start**, **proceed**, and **stop** which can be used to characterize the progression of an event with greater precision (cf. [André et al. 88]). By means of an incremental recognition strategy, based on these predicates, events can be recognized simultaneously as they occur in the underlying image sequence.

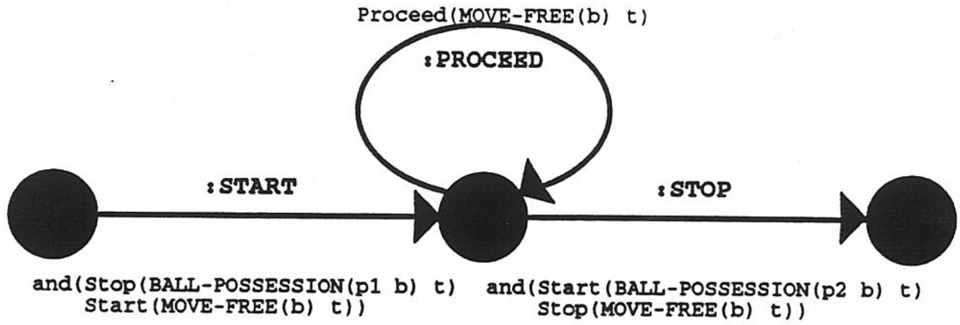

Figure 6: Course diagram

Labeled directed graphs with typed edges, so called *course diagrams*, are used to model the prototypical progression of an event. Figure 6 shows a simplified course diagram for the concept BALL-TRANSFER. It describes a situation in which a player passes the ball to a teammate. The event **starts** if a BALL-POSSESSION event stops and the ball is free. The event **proceeds** as long as the ball is moving free and **stops** when the recipient has gained possession of the ball. The recognition of an occurrence can be thought of as traversing the course diagram, where the edge types are used for the definition of our basic event predicates.

```
(defevent BALL-TRANSFER(p1*player b*ball p2*player)
   :subconcepts
   BALL-POSSESSION(p1 b) [I1]
   MOVE-FREE(b) [I2]
   BALL-POSSESSION(p2 b) [I3]
   :temporal-relations
   [I1] :m [BALL-TRANSFER]      [I1] :m [I2]
   [I2] :e [BALL-TRANSFER]      [I2] :m [I3])
```

Figure 7: A simple interval-based concept definition

Figure 7 shows the corresponding interval-based representation of the event concept. The definitions of the different temporal relations between two intervals are summarized in figure 8.

Course diagrams rely on a discrete model of time, which is induced by the underlying image sequence. They allow incremental event recognition, since exactly one edge per unit of time (i.e., at video rate — 25 frames per second) is traversed.

X-?-Y				Y	Y	Y		
before	b	X						
meet	m	X	X					
overlap	o	X	X	X				
finished by	fi	X	X	X	X	X		
contains	c	X	X	X	X	X	X	X
start	s			X	X			
equal	e			X	X	X		
started by	si			X	X	X	X	X
during	d				X			
finish	f				X	X		
overlapped by	oi					X	X	X
met by	mi						X	X
after	a							X

Figure 8: Possible temporal relations between two intervals (c.f. [Allen 84])

4 Utilizing Temporal Reasoning

In general the specification of a course diagram seems to be more lavish, because an interval-based concept definition is better readable. Another drawback is that it is difficult to draw inferences like *"the occurrence of an event E_1 implies the occurrence of another event E_2"* (c.f. [Neumann 89]). So the problem is that *reasoning* about events and event models based on specialization and decomposition implies the use of (complete) temporal intervals, but incremental event *recognition* has to deal with data related to single points in time.

As a solution to this problem we suggest to use both representation formats[2] and to define an automatic translation procedure from interval-based concept definitions into course diagrams.

4.1 Constraint-Based Temporal Reasoning

The automatic construction of course diagrams can be seen as a temporal reasoning problem, which can be solved with temporal constraint propagation techniques. So the idea is to utilize a temporal reasoning system for the implementation of the translation procedure. The reasoner we currently use is the TIMELOGIC system (c.f. [Koomen 87]), that is basically an implementation of the constraint propagation algorithm described in [Allen & Koomen 83]. Intervals and interval constraints given in the concept definition form the input for the temporal reasoner, that computes the temporal relations between each pair of intervals and detects inconsistencies in the relation network. If there are no disjunctive relations between the intervals the TIMELOGIC system is able to compute the temporal order of all start points and end points of the intervals. This projection onto the temporal axis can easily be used for the construction of a course diagram.

[2] A dual representation of motion concepts is also described in [Walter 89]. On the one hand event models and recognized instances are stored in a KL-ONE-like representation format which is mapped onto a relational database. ATN's (c.f. [Woods 70]), which, however, are not generated from the KL-ONE net, are on the other hand used for the recogniton of events.

```
t0 - START:    BALL-POSSESSION(p1 b)
t1 - END:      BALL-POSSESSION(p1 b)
     START:    MOVE-FREE(b)  BALL-TRANSFER(p1 b p2)
t2 - PROCEED: MOVE-FREE(b)  BALL-TRANSFER(p1 b p2)
t3 - END:      MOVE-FREE(b)  BALL-TRANSFER(p1 b p2)
     START:    BALL-POSSESSION(p2 b)
t4 - END:      BALL-POSSESSION(p2 b)
```

Figure 9: Conditions for the course diagram

For the example given in figure 7 two temporal relations `[BALL-TRANSFER] :m [I3]` and `[I1] :b [I3]` will be calculated first. Figure 9 shows the final ordering of the start and end points. Only those time points related to the defined event have to be considered for the course diagram (c.f. figure 6). The conditions for `t1` and `t3` are modelled as transitions from one node to another and the `:PROCEED` condition for `t2` results in a loop.

```
(defevent PENALTY-KICK(p*player b*ball g*goalkeeper)
   :subconcepts  RUN-UP(p) [I1]  SHOOT(p b) [I2]
                 MOVE(g)   [I3]  PARRY(g)   [I4]
   :temporal-relations
   [I1] :s [PENALTY-KICK]    [I1] (:b :m) [I2]
   [I3] :d [PENALTY-KICK]    [I3] :m      [I4]
   [I4] :f [PENALTY-KICK]    [I2] :f      [I3])
```

Figure 10: Coping with disjunctive relations

In general, disjunctions of temporal relations might occur explicitly or implicitly in a concept definition (c.f. figure 10). [3] A direct projection onto the temporal axis is not possible if there are any disjunctive relations between intervals, i.e., if temporal constraints are not strong enough to induce a total ordering on all start and end points. Disjunctive temporal relations imply that there are several ways of decomposing an event into subconcepts. Each possible temporal decomposition has to be captured by an own course diagram. A specific decomposition can be obtained by adding the appropriate temporal constraints. TIMELOGIC provides a context mechanism which can be utilized in order to enumerate all possible temporal decompositions.

In the example given in figure 10 one disjunction is stated explicitly in the definition and a second (implicit) disjunction is calculated by the reasoner. Figure 11 and 12 show the context tree and the four possible decompositions. The solutions of the constraint network correspond to the leafs of the context tree, i.e., those contexts in which all disjunctions are resolved (Context 1 3, 4, and 5 in our example).

Constraint propagation in TIMELOGIC only ensures path consistency (c.f. [Allen & Koomen 83]). Thus the reasoner can not detect inconsistencies like in the temporal constraint network given in figure 13. Anyhow, the process of resolving the disjunctions guarantees that all possible solutions, if there are any, will be enumerated. Despite its computational complexity — the algorithm is exponential — the method is useful for our application. We can assume that, the number of intervals in a single concept is quite small (< 10), because of the hierarchical organization of the knowledge base. Run time is also not critical, since the translation only has to be done once and before any event recognition happens.

[3] General disjunctive relations are not allowed in NAOS (c.f. [Neumann 89]), i.e., the system is restricted to the so-called *point algebra* (c.f. [Vilain & Kautz 86]).

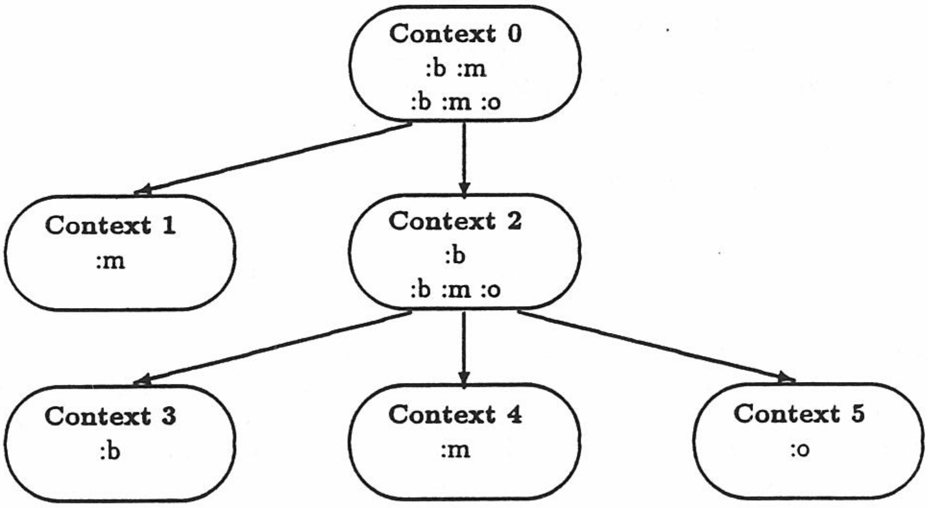

Figure 11: Context tree for the example concept

```
| PENALTY-KICK-C1 |                   |-   PENALTY-KICK-C3    -|
|RUNUP|SHOOT|                         |RUNUP|        |SHOOT|
    |- MOVE -|PARRY|                           |- MOVE -|PARRY|
0  1  2      3     4                  0      1  2  3     4     5

|-  PENALTY-KICK-C4 -|                |- PENALTY-KICK-C5 -|
|RUNUP|   |SHOOT|                     |RUNUP| |SHOOT|
       |- MOVE -|PARRY|                   |-  MOVE   -|PARRY|
0      1  2     3     4               0  1  2 3     4     5
```

Figure 12: Solutions of the temporal constraint network

4.2 Extending the framework

In order to rule out *"useless"* concept definitions, additional general temporal constraints might be applied to event concepts.

- If a decompositional part of an event could happen *after* the event itself, it would be difficult to define a clear semantics. Certain statements about present events could only be made in the future.
- If the definition of an event concept relies on a decompositional part, that must happen *before* the event, the system must not only remember the near past but all instances of a certain type of event.
- In order to avoid strange effects during the recognition and simultaneous description of an event it would be useful to forbid *"gaps"* in the decomposition, i.e. there must be no sub-interval of an event during which nothing has to happen.

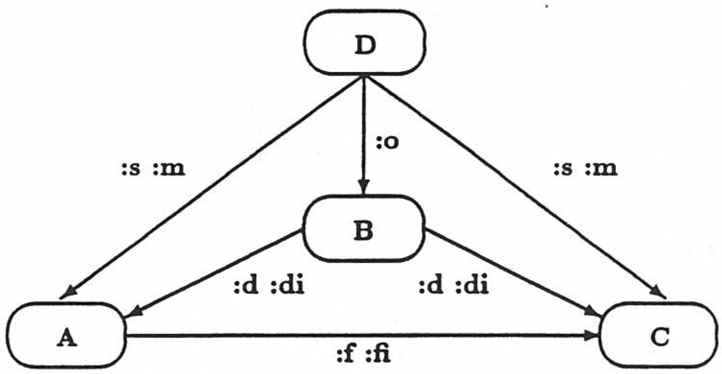

Figure 13: Inconsistent temporal constraint network

Constraints of this type can easily be added automatically to any concept definition. The temporal reasoner than takes the burden to satisfy them.

So far only qualitative temporal aspects of an event and its decompositional parts have been considered. Within the TIMELOGIC system it is possible to specify minimal and maximal relative durations, i.e., the length of a duration can be measured with respect to the duration of another interval. The TEMPORAL INFERENCE ENGINE described in [Tsang 87] even allows for the specification of minima and maxima for absolute durations.

Durational constraints can force stronger relational constraints and may lead to an inconsistent constraint network. Allthough relational and duration constraints are propagated to one another in the systems mentioned above, they can only detect some but not all inconsistent situations caused by durational constraints. In our approach a different strategy is applied. The handling of durational constraints is delayed until all solutions of the (qualitative) temporal constraint network have been computed. Finally each possible decomposition is treated individually with respect to the remaining metric constraints. As proposed in [Malik & Binford 83] this task is carried out using linear programming with the *simplex* method.

5 Summary

Our approach towards *simultaneous* scene description emphasizes concurrent image sequence evaluation and natural language processing, carried out on an *incremental* basis, an important prerequisite for real-time performance. High-level scene analysis as it is employed in VITRA is based on incremental event recognition using course diagrams.

In this contribution we have argued that in fact a dual representation of motion concepts is needed, because events are not only to be recognized. During language production the system has to reason about implications of specific motion events and the relations between different occurrences. Interval-based event models, based on specialization and temporal decomposition, are best suited for this kind of reasoning. We have shown that, given the latter representation format, the automatic construction of course diagrams can be seen as a temporal reasoning problem. Based on temporal constraint propagation techniques a translation procedure is defined and the representation formalism can be extended in order to cope with disjunctive temporal relations, general qualitative restrictions, and durational constraints.

The current implementation relies on TIMELOGIC, a basic temporal reasoning system. A more sophisticated temporal reasoner, like the one described in [Tolba et al. 91][4], could even simplify the task, since the solutions of the constraint network can be provided directly and a more advanced treatment of metric constraints is possible.

The methods presented here are applied for the investigation of short sections of soccer games and of traffic scenes. A large knowledge base, with more than 100 event concepts is under development.

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